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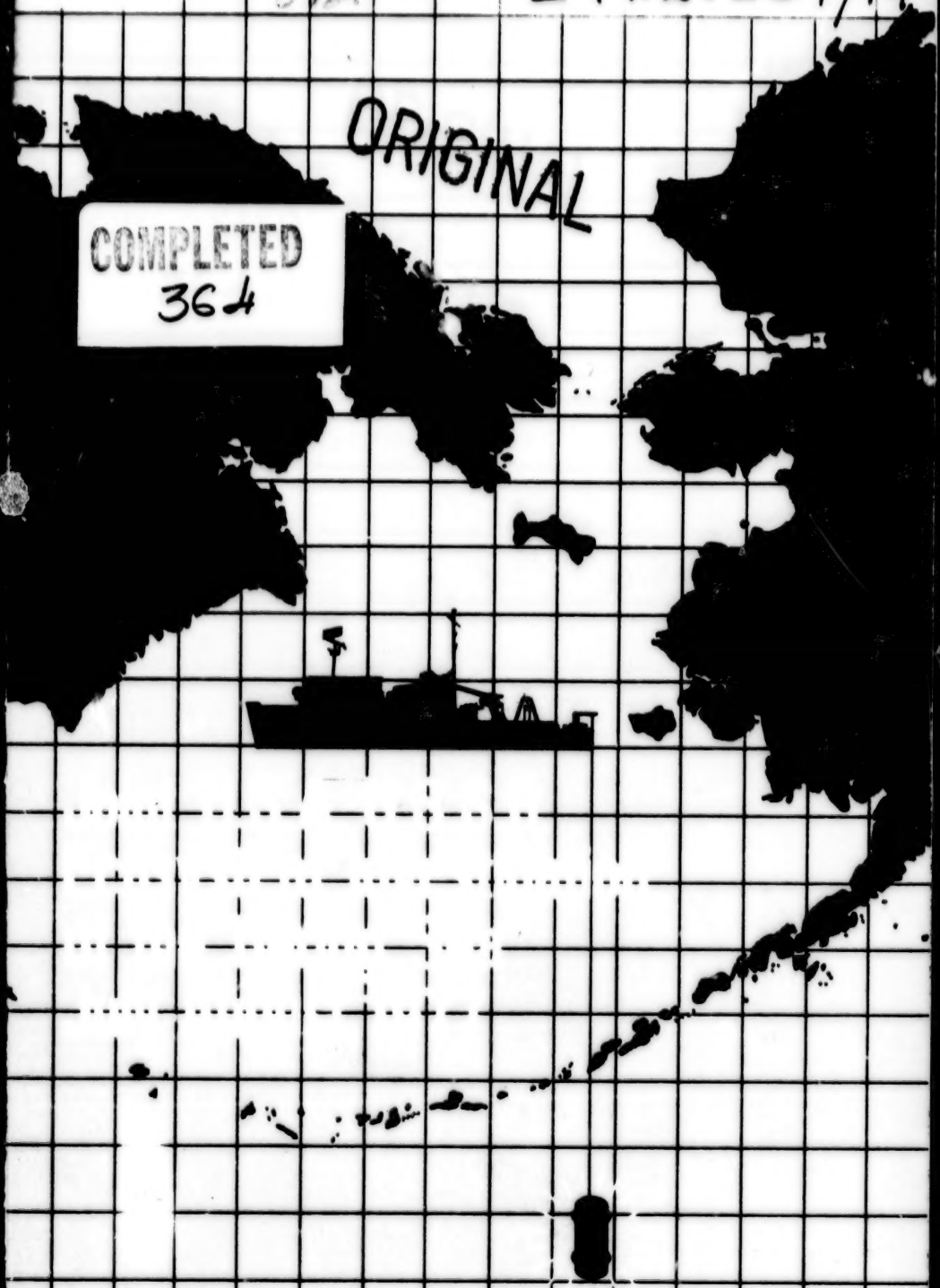

USA-USSR Agreement On Cooperation In The Field
On The Protection Of The Environment

USSR State Committee on Hydrometeorology and Environmental Control

United States Department of the Interior, United States Fish and Wildlife Service

Ecological Studies on the Ecosystem of the Bering Sea; Preliminary Observations Obtained by a Joint USSR-USA. Expedition in the Eastern Bering Sea and Results of this Initial Scientific Investigation During July-August, 1977 on the M/V Volna.

Project 02.05-41 Biosphere Reserves
"Bering Sea Studies"

Expedition Report prepared jointly by an Editorial Board consisting of American and Soviet scientists. Due to differences in language, style, and manuscript preparation, the American version will differ minimally from the Russian in terms of text, but the graphs, tables, charts, and maps were assiduously duplicated in both volumes.

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I

TABLE OF CONTENTS

	Page
Editorial Board	i
Editor's Forward: Dr. Yu.A. Izrael	ii
Overview: Prof. Dr. J.J.A. McLaughlin and Dr. A. V. Tsyban	iv
LIST OF TABLES	x
LIST OF FIGURES	xii
ACKNOWLEDGEMENTS	xvi
LIST OF PARTICIPANTS	xvii
I. INTRODUCTION-1977 Expedition	
Study Framework	1
Expedition and Region of Study Descriptions	2
Bering Sea Geography	3
Circulation	4
Ice Formation	8
Productivity	9
II. METHODS AND MATERIALS	
Sampling Method	
A. Location of Study Area	12
B. Meteorology(USSR)	12
1) Actinometric Observations	13
C. Atmospheric Chemistry(USSR)	14
1) Radioactive Nuclides	14
2) Sulfur Dioxide	20
3) Trace Metals	23
4) Hydrocarbons	25
5) Benzo(a)pyrene	27

Page

D. Hydrologic 28

1) Physical 28

(a) USSR Methods 28

(b) USA Methods 34

(c) Chemical 35

1) Water 35

(a) Nutrients 36

1) USSR 36

(a) Phosphates 36

(b) Nitrites 36

2) USA 37

(a) Nutrients 37

Trace Metals

1) USSR 49

2) USA 50

Surface Microlayer Samples 51

Water Column Trace Elements

1) USSR 53

Trace Elements in Plankton 54

Low Molecular Weight Hydrocarbon in Water (USA) 57

High Molecular Weight Hydrocarbons and Benzo(a)pyrene (USSR) . 59

Hydrocarbons and Benzo(a)pyrene (in Plankton) (USSR) 59

Biological

1) Chlorophyll a (USA) 60

2) Phytoplankton and Zooplankton (USSR) 60

Page

III. RESULTS

Meteorology

1) Synoptic Processes and Weather Conditions 61

Actionmetric Observations 62

Atmospheric Chemistry

1) Radioactive Materials 74

2) Sulfur Dioxide 74

3) Trace Metals 74

4) Hydrocarbons 78

5) Benzo(a)pyrene 78

Hydrologic 78

Geostrophic Flow Estimation 95

Light 109

Chemical

1) Water 113

Oxygen 114

Nutrients 114

Trace Elements in Seawater 135

Plankton 141

Low Molecular Weight Hydrocarbons 150

Biological

(1) Chlorophyll a 161

a) Temporal Variation in Chlorophyll a and Nutrients 164

Page

(2) Phytoplankton and Zooplankton 167

(a) Distribution of Dominant Species of Phytoplankters 167

(b) Distribution of Dominant Species of Zooplankters 168

IV. DISCUSSION 185

Weather Conditions and Atmospheric Chemistry 185

Temperature 207

Light 210

Nutrients 212

Circulation 216

Upwelling Phenomena 218

Plankton 226

V. SUMMARY 232

VI. LITERATURE CITED 233

VII. APPENDICES

1) Appendix 1 247

2) Appendix 2 257

3) Appendix 3 264

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01

Editor's Forward by Dr. Yu. A. Izrael

Research from the last several decades has shown that human activity quite often influences the condition of marine ecosystems negatively. Among these negative consequences is not only the unfounded use of ocean resources but also especially anthropogenic changes in the chemical and biological characteristics of the marine environment. The temperature, gas and chemical regime which has come to be in the ocean across many years of geological epochs and which is favorable for the development of life is being destroyed in connection with the active influx of pollutant substances into the marine environment. Thus, currently there have been identified approximately 4,000,000 chemical substances of them about 30,000 various combinations are released by chemical industry. Many of these are toxics and which are released under the control of man and circulate into the environment.

The pollutant substances which enter the world oceans are not distributed evenly in it and there are formed zones of intensified levels in the coastal areas in the euphotic layer, where the fundamental mass of living substances are concentrated. The chemical toxicants are becoming at the present time a powerful and constantly acting ecological factor which is transforming marine ecosystems as a result of organic substances, depends upon the negative consequences of human activity. Thus, the annual decrease in the production of nektons in the world ocean is approximately a quantity of 20 million tons.

The appearance of pollution, the danger of an increase of the negative anthropogenic influences on the ocean have now led to an activization of natural protection activities in the ocean's zones.

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First and foremost concepts of a scientific approach to the development of criteria for quality of the marine environment are being created and the evaluation of the potential of marine ecosystems taking into consideration predicted and already existing changes in anthrogenic activity on the ocean. The contours of the most important oceanological problem have been defined: This is the problem of the pollution of the ocean and ecological consequences of this. In spite of the many various forms of life in the world ocean and the presence of different conditions in the environment, a wide spectrum of ecological consequences of pollution can be identified and brought to a scientifically founded harmonic system, which forms the theoretical basis for ecological monitoring of the ocean[1]. Ecological consequences of ocean pollution form a whole chain of interrelated reactions, the most apparent appearance of which is the transformation of natural biogeocenoses, the destruction of carbon nitrogen, and sulfur cycles the decrease in biological productivity and the change in the genetic structure of cells.

[1] Izrael, Yu. A., A. V. Tsyban. The problems of monitoring of ecological consequences of the ocean pollution, Hydrometeoizdat, 1981.

Overview by Prof. Dr. John J.A. McLaughlin and Dr. Alla V. Tsyban

From July 29 to August 12, 1977 the first Soviet/American expedition in the Bering Sea was carried out onboard the Soviet Research Vessel "Volna". Investigations were carried out in the polygon (57° 31 minutes north latitude and 168° 10 minutes west longitude), situated to the northwest of Bristol Bay and to the south of St. Lawrence Island. The sea's depth in the region varied from 2,700 meters in the huge southern portion of the continental slope (Zhemchug Canyon) to 30 meters in the northeastern portion of the shallow coastal zone.

During the joint expedition at 51 stations, while comprehensive hydrological, hydrochemical and hydrobiological activities were carried out there were also carried out intercollaboration of methods of determining several hydrographical and hydrochemical parameters. Results of the expedition's investigations permit the determination of three types of water mass in the research region: the coastal, the shelf and the water mass of the Alaskan current. Coastal waters having low salinity and expressing a thermocline and helocline, were situated to the northeast zone of the polygon. Shelf waters which are characterized by sharp temperature and saline stratification were located to the south of St. Lawrence Island and encompassed 100 meters isobath. The waters of the Alaskan current which have relatively weak temperature and slight salinity stratification are located to the south of this border to the boundaries of the polygon and also along the continental slope.

Considerably density stratification, characteristic of shelf waters, apparently create an effective barrier for the vertical transport of substances. The depth of the mixed layer, the level of the euphotic zone and the concentration of nutrients increased in the direction of

TK

the Continental Slope.

The evaluation of geostrophic flow shows the presence of a general cyclonic circulation directed clockwise towards the region of the "principal" water mass and also in the lower part of the shelf zone. A general northerly direction of the flow towards the Bering Strait has been discovered. At the same time a counter current oriented towards the south along the Alaskan coast was observed.

It is necessary to note that the maintenance of cold water masses lower than zero degree centigrade in the zone situated to the southwest of St. Lawrence Island testifies to the unequal distribution of the water flow towards the north. There also occurs here a certain replenishment of waters due to the principal water mass which is warmer and richer in nutrients. Favorable conditions for the development of plankton occur at the boundary of a cold water mass.

Results of the study of the concentration and distribution of nutrients in addition to the evaluation of the geostrophic flow rate shows the presence of upwelling in the region of the continental slope and particularly in the Zhemchug canyon region. An increase of primary production to several grams of carbon under one meter squared was accompanied by a decrease of nutrient concentration in the euphotic zone along the continental shelf. The content of silica dioxide determined levels for chlorophyll in this region. Nitrogen and phosphorus decreased from seawater in an average ratio of 18.8 to 1, nitrogen and silica dioxide - in an average proportion of 1.3 to 1.

An active inflow of nutrients creates a fund for primary production of organic matter in the upwelling zone and determines favorable conditions

for secondary production. In this respect the region of the continental slope, which comprises 13% of Bering Sea area, can be regarded independently from the point of view of primary production of the entire basin.

It is necessary to note that the results of the Expedition's investigations corrected the magnitude of primary production for the summer period to 22% (50 x 10^6tons). Previous authors had established different values[1]. Thus, the primary production in the Bering Sea for the summer period comprises (60 x 10^6tons).

Among phytoplankton of the research area dominated oceanic species. A typical oceanic species Coscinodiscus oculus iridis shows maximum population in deep depths of the shelf region and also in cold waters with low salinity. At the edge of the shelf the population of this species was insignificant.

The population of the dominant forms of zooplankton achieved maximum values (9,500 per meter squared) in the edge region of the shelf, minimum in the seas (2500 cu meters) were discovered in the deep water zone.

The distribution of several oceanic forms of zooplankton (Calanus cristatus, Eugatus bungii, Thysanoessa longipes) were limited to the deep water portion of the polygon near the shelf's edge. Cosmopolitan species Oithona similis showed maximum population at the marginal region of the shelf, the population of this species sharply decreased above the shelf. Neuritic species, Acartia longiremis and hetrotropic organisms dominated above the shelf and also in the shallow region of the polygon.

[1]McRoy, C.P. and J.J. Goering. The Annual Budget of Primary Production in the Bering Sea. Marine Sci. Comm. 1976 (2)5: 255.267.

The species composition of the plankton's biomass inhabiting the shallow water part of the polygon changed over time less than these characteristics of the plankton along the edge of the shelf in the deep water region of the polygon. This phenomenon is associated with the active dynamics of the waters near the edge of the shelf in the zone of the transectional currents influence. In the shallow water portion of the polygon temperal changability of species composition and the plankton's biomass was substantially less than in the deep water part of the polygon. This can be explained by the active dynamics of the waters near the shelf's edge in the zone of the transectional current's influence. The results of comprehensive investigations elucidated chemical conditions of the water mass and also the new water layers of the atmosphere under conditions for a specific year.

For the first time for the Bering Sea there have been carried out thoroughly extensive examinations of the content and distribution of trace elements, metals and hydrocarbons, including low molecular weight benzo(a)pyrenes, in the water column plankton and the oceanic atmosphere. A comparison of the expedition's materials with data of investigations from other regions of the world's ocean testifies to the favorable ecology of this basin and to its relative purity of its ecosystem (a so-called "pristine" ecosystem). Observed spectrum of concentrations of hydrocarbons, trace elements, sulphur dioxide corresponded to background levels and were characteristic of open regions of the ocean. However, the question of the source of distribution and accumulation of benzo(a)pyrene in the Bering Sea ecosystem remains unexplained and requires further investigation.

It is necessary to note in particular the concentration factors of metals and particularly of benzo(a)pyrene in planktonic organisms. This fact stresses the ability of marine biota to accumulate chemical compounds even in a relatively pure environment and accumulate them in

concentrations considerably greater than in sea waters. The chemistry of the nearwater layer of atmosphere and the thin nearsurface microbiotope of the ocean are closely related. As a result of specific continuous physical - chemical processes in the region of the interaction of the ocean and atmosphere in the surface film and the adjacent thin layer of water, there are accumulated chemical elements and organic substances which are transported to the surface of the sea from the water column. Elimination of these compounds from the marine environment in the process of ocean aerosol formation results in an enrichment of the oceanic atmosphere by chemical elements and their pollution especially in coastal regions and internal seas. Taking into consideration the possible impact of atmospheric transports and precipitation of pollutants on the state of the Bering Sea's ecosystem, a detailed examination of the biological and chemical processes in the region of the near surface microbiotop seems to be both topical and necessary in the light of the tasks of ecological monitoring of the ocean.

Summarizing the aforementioned, it is necessary to make note of the importance of the Expedition's investigations that have been carried out from the point of view of studying the new processes in the Bering Sea, the evaluation of the state of its ecosystem and the development of long-term observations for the establishment of a system of background monitoring of the ocean and the study of the ecological consequences of its pollution.

It should be noted by all that the presence of pre-doctoral and pre-masters students working side-by-side with their Russian and/or

American counterparts produced many friendships which we trust in the future will lead to a better understanding of the inherent human concern for the work, ideals and objectives of all mankind. It is our belief that the small contributions made during this expedition will hopefully contribute towards a totally world-wide system of scientific interdependence. As we progress into the 21st Century, we must be more aware that the earth does represent the equivalence of a home and must be treated in a manner such that it could weather the onslaught of great variations of prosperity and pollution and remain a balanced ecosystem.

It is our deep hope, that of all the creatures on the earth, man with his intelligence and free will can transcend the trials placed upon his mind, body and soul.

List of Tables

Page

1. Positions, Sampling Dates and Depth of Stations of the Bering Sea Expedition, 1977 18

2. Trace Metal Content of FPA-15 Filters 24

3. Comparison of Data Collected 39

4. Meteological Data of Bering Sea 65

5. The percent distribution of total and low cloudiness during the daylight hours 68

6. Diurnal Sums of incoming and reflected solar radiation 69

7. The Daily Concentration of Pb^{214} and Pb^{212} in the study area . . . 75

8. The atmospheric concentration of sulfur dioxide near the sea surface 76

9. The atmospheric concentration of trace metals near the surface of the sea 77

10. Sample locations, times, average wind velocity and temperature. . 79

11. Hydrocarbon Data 79

12. Anomaly of dynamic depth 100

13. Observed light extinction coefficients 110

14. Concentrations of copper in Bering Sea Filtered Sea Water 138

15. Concentrations of lead in Bering Sea Filtered Sea Water 139

16. Results of analysis of water 142

17. Biomass of plankton 144

18. Content of elements in plankton 145

19. Content of elements in surface plankton 147

20. Accumulation of coefficients of elements in plankton 148

21. Content of elements in surface plankton 149

22. Concentration of benzo(a)pyrene in water 159

23. Changes and rates of change in euphotic zone integrated nutrients and chlorophyll a at stations 165

Page

24. Frequency of encounter of dominant species of phytoplankters 171

25. Population of the dominant species of zooplankters 174

26. Dominant species of phytoplankters 180

27. Literature data on the concentrations of sulfur dioxide in the ocean atmosphere 190

List of Figures

		Page
1.	Major geographical features of Bering Sea	5
2.	Location of stations and station labeling	17
3.	Relation between concentrations determined by two methods	21
4.	Correlation between USA-USSR thermometric data	31
5.	Correlation between USA-USSR salinity data	32
6.	Soviet and American pH data	47
7.	Comparison of Soviet and American oxygen data	48
8.	Chart of average surface pressure, August 1977	63
9.	Chart of average baroclinic topography August 1977	64
10.	Daily curve of total and reflected radiation August 8, 12, 1977	66
11.	Frequency of occurrence of various cloud types	70
12.	Daily variation in the total radiation 30 July - 12 August 1977	70
13.	Daily variation in albedo	73
14.	Chromatogram of Filter F-2	81
15.	Vertical distribution of temperature and salinity along Trans. 1	82
16.	Vertical distribution of temperature and salinity along Trans. N1.2	83
17.	Vertical distribution of temperature and salinity along Trans. 4	84
18.	Vertical distribution of temperature and salinity along Transect	85
19.	Temperature isopleths for the Western North-South (W, N.S.)transect	87
20.	Salinity and temperature profiles	89
21.	Bottom temperature isopleths	90
22.	Salinity isopleths	92
23.	Salinity-temperature plot: Stations 1-24	93
24.	Salinity-temperature plot: Stations 25-48	94
25.	Location of water masses in study area	96

Page

26. Sigma-t isopleths West to East transects 97

27. Sigma-t isopleths from the Western, North-South transects 98

28. Sigma-t isopleths from the Eastern, North-South transects 99

29. Geostrophic current vector field relative to the 25 dbar surface 106

30. Geostrophic current vector field relative to the 50 dbar surface 107

31. Geostrophic current vector field relative to the 75 dbar surface 108

32. Ambient light intensity at station 115

33. Mixed layer-euphotic zone relationship on a North to South transect . . 116

34. Distribution of oxygen (ml/l) along Transect No. 1 117

35. Distribution of oxygen (ml/l)along Transect No. 2 118

36. Distribution of oxygen (ml/l) along Transect No. 4 119

37. Spatial distribution of nitrites 120

38. Distribution of oxygen (ml/l) and silicon (ug/l) along Trans. 3 121

39. Distribution of silicon (ug/l) along Transect No. 1 122

40. Distribution of silicon (ug/l) along Transect No. 2 123

41. Distribution of silicon (ug/l) along Transect No. 2 124

42. Nitrate isopleths from Northern and Southern transects 126

43. Nitrate isopleths from the Western transects 127

44. Nitrate isopleths from the Eastern transects 128

45. Phosphate isopleths from Northern and Southern transects 130

46. Phosphate isopleths from Eastern and Western transects 131

47. Geometric mean regression of total nitrogen on phosphate 132

48. Geometric mean linear regression of total inorganic nitrogen on silica as soluble silicates 133

49. Silica isopleths from Northern and Southern transects 136

50. Silica isopleths from Eastern and Western transects 137

51. The average concentration of copper and lead in the upper 25 meters 140

Page

52. Vertical profiles of methane 152

53. Vertical profiles of temperature 153

54. Vertical profiles of salinity 154

55. Content of hydrocarbons in plankton in the water 156

56. Chromatograms of water samples 157

57. Distribution of depth average chlorophyll a 160

58. Density stratification and chlorophyll a vertical distribution relationship 162

59. Pycnocline stability and pycnocline associated chlorophyll concentration relationship 163

60. Spatial distribution and relative abundance of dominant forms of phytoplankters on the polygon - Stage 1 169

61. Spatial distribution and relative abundance of dominant forms of phytoplankters on the polygon in the Bering Sea - Stage 2 170

62. Spatial distributions of temperature and salinity on the study polygon in the Bering Sea 172

63. Spatial distribution of nitrites on the study polygon in the Bering Sea 173

64. Population distributions of O. similis and E. bungii 177

65. Population distributions of A. longiremis and P. elongatus 178

66. Population distributions of S. elegans and C. plumchrus 179

67. Distribution of biomass of plankton along the transects in the study polygon in the Bering Sea 182

68. Trajectories of air masses in the Bering Sea during the period July 30 to August 12, 1978 188

69. Relationship between content of aerosols in the air and concentrations of sea salt in air over the surface of the water 193

XII

Page

70. Variation in particle size of mineral and organic aerosols 198

71. A real extent of ice cover in the Bering Sea 1973-1978 209

72. Distribution of extinction coefficients 211

73. Relationship between the change in chlorophyll a concentrations and changes in ammonia and silica as soluble silicate concentrations 215

74. Comparison of nitrate and salinity isopleths 221

75. Zhemchug Canyon bathymetry and euphotic zone integrated nitrate concentrations 222

76. IBM computer and interface - Interocean probe data acquisition system 249

77. IBM Computer and interface - Interocean probe system data acquisition loop 250

78. IBM computer and interface - Technicon Autoanalyzar data acquisition system 252

79. Logic circuit for IBM-Technicon system 254

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I. INTRODUCTION

Study Framework

Marine pollution is primarily associated with 10 percent of the world's ocean namely the continental shelf (McLaughlin and Alexander 1973). The continental shelf of the Bering Sea, which comprises approximately 44% of the total area of this sea, is one of the most productive regions of the world (McRoy and Goering 1976; Hattori and Wada 1974; Hood and Kelly 1974). No significant direct contamination of the Bering Sea by manmade materials is yet apparent except for some wind borne material (Hood and Kelly 1974). How long this will remain true depends primarily upon the development of natural resources and industry by the Soviet Union and the United States not only along the perimeter of the Bering Sea but also on the shelf itself. In view of the impending development of the region there is an urgent need for the establishment of a Bering Sea data bank. The nature of these data must be such that the biological health of the area prior to development can be validly documented and at the same time be capable of inclusion in predictive ecosystem models. To accomplish this, a monitoring program should be established and the success of this program will, in part, depend on joint cooperation between Russian and American scientists.

The U.S.-U.S.S.R. oceanographic expedition to the Bering Sea (summer 1977), made possible through the efforts of the U.S.-U.S.S.R. Joint Committee on

Cooperation in the Field of Environmental Protection (Project 02.05-41 Biosphere Reserves), was an active expression of concern for the protection of this highly productive and mutually exploited resource. The expedition was developed to examine a region of the Bering Sea west of a known area of high productivity where there existed a substantial void in baseline data.

The goals of the expedition as outlined in the expedition's protocol were:

(1) To collect selected baseline physical, chemical and biological data;

(2) To delineate sources of nutrients to the study area as a preliminary explanation of the mechanisms which effect productivity;

(3) To determine the presence and quantity of hydrocarbon and metal pollutants; and to evaluate their movement in relation to the transport of nutrients;

(4) To evaluate and intercalibrate oceanographic methodology with the Soviet scientific personnel.

Expedition and Region of Study Descriptions

In fulfillment of the U.S.-U.S.S.R. agreement for the Protection of Environment: Biosphere Reserves, the protocol for a cooperative oceanographic expedition to the mutually exploited resources of the Bering Sea was developed at meetings in Moscow, April 1977. The head of the scientific delegation representing the United States at this series of meetings was Dr. Robert Putz of the U.S. Fish and Wildlife Service, Department of the Interior.
Dr. John J. A. McLaughlin of Fordham University was the Chief U.S. scientific negotiator for protocol development.

The protocol that resulted from these meetings defined the study area, sampling methods and analytical techniques for the expedition. The region selected for study was that area within the general confines of 57°31'N-63°00'N and 168°10'W-178°10'W. This region is northwest of the highly productive Bristol Bay and south of St. Lawrence Island. The bathymetry of this region ranges from continental slope at the southern extent with a maximum depth of 2,700 m in the Zhemchug Canyon to less than 30 m depth in the northeast coastal zone. The volcanic St. Matthew Island is located in the approximate center of the study area. The expedition was conducted aboard the Soviet Hydrometeorological Institute research vessel Volna. Nine U. S. scientific personnel under the direction of Dr. John J. A. McLaughlin were present on the expedition. The Soviet scientific personnel (28) under the direction of Dr. L. K. Konopkin were also present on the expedition. The expedition began in late July 1977 at Dutch Harbor, Alaska where the U.S. scientific team, analytical equipment and power conversion system were taken aboard the Volna. Fifty-one oceanographic stations were sampled on a 2,600 mile (4,186 km) course over the northeastern shelf of the Bering Sea from July 29 - August 12, 1977.

Bering Sea Geography

The Bering Sea takes its name from the Russian, Vitus Bering, who first explored the area in two cruises during 1725 - 1743. The Bering Sea (Fig. 1) lies within latitudes 51°N and 66°N and longitudes 157°W and 163°E. The northern and southern physical boundaries are the Bering Strait and the Aleutian Island chain. The eastern and western boundaries are the North American and Asian continents, respectively. The Bering Sea is the second largest of the

relatively confined seas; the Mediterranean Sea being the largest (Shor 1966). Although it is often referred to as an extension of the North Pacific (Hood and Kelly 1974), the volcanically formed shallow sills of the central and eastern Aleutian chain effectively separate the Bering Sea from the Pacific Ocean. The Bering Sea has a total volume of $3.7 \times 10^6 km^3$ and an average depth of 1,636 meters (Shor 1966). Of the total $2.3 \times 10^6 km^2$ surface area, 44% is shelf, 43% is abyssal and 13% is continental slope (Hood and Kelly 1974). Most of the continental shelf is less than 200 m deep. This shelf area is also referred to as the Epicontinental Bering Sea (Hattori and Wada 1974). This area was land as recently as 20,000 years ago (Hood and Kelly 1974a). The water over the shelf of the Bering Sea, delineated by the continental shelf margin extending from Samalga Pass in the Aleutian Islands to Cape Navarin in the Siberian Coast, has been defined as the Eastern Bering Sea (McRoy et al. 1972) and will be referred to as such here. The section of the Bering Sea east of a line between Nunivak Island off the Alaskan Coast and the Pribilof Islands will be considered here as Bristol Bay as defined by Coachman and Charnell (1977). Relatively steep slopes (4°-5°) occur upon the edge of the shelf area and lead to the deep (3,000m) Aleutian Basin (Shor 1966).

Circulation

It is generally accepted that the source of seawater into the Bering Sea is from the Alaskan Stream (Ohtani 1974; Hughes et al. 1974; Favorite 1974; Takenouti and Ohtani 1974; Reed 1971; Coachman and Charnell 1977). The Alaskan Stream originates off the northwest coast of Japan where the Oya Shio and Kuro Shio currents meet. Prevailing winds drive the Kuro Shio across the Pacific

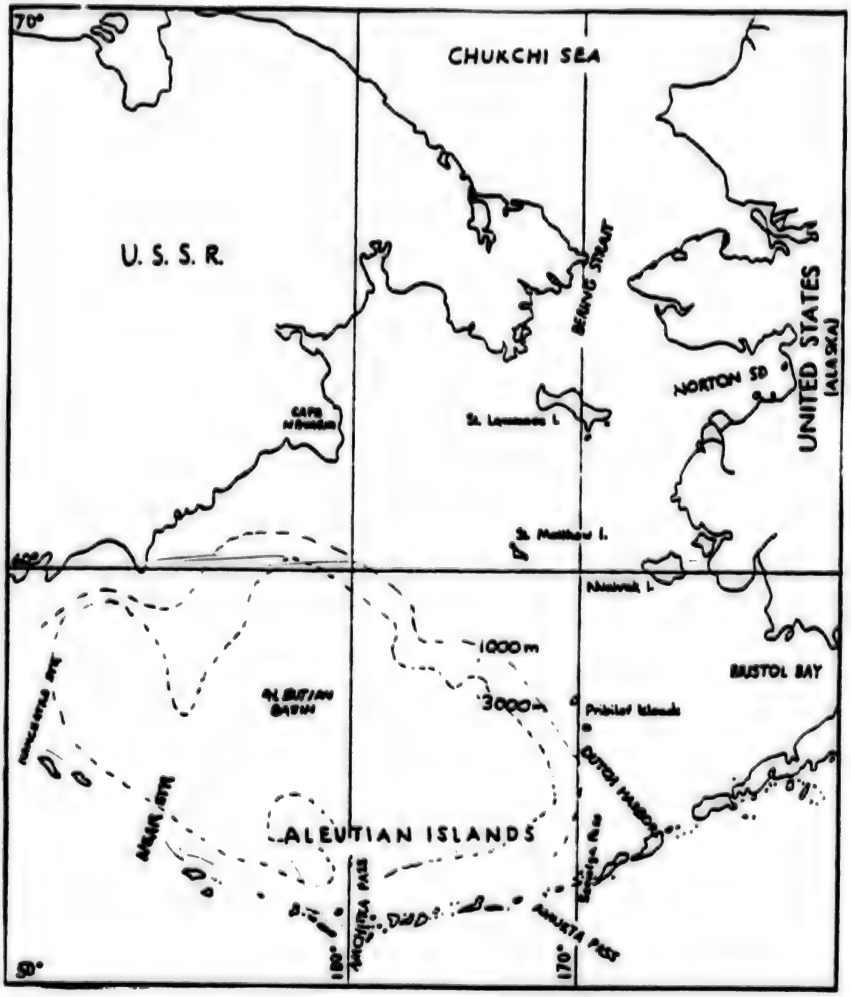

Figure 1. Major geographical features of Bering Sea. Dashed lines are bathymetric contours.

north of 40°N. The current then divides and a portion of it proceeds south and forms the California Current. The remainder proceeds north into the Gulf of Alaska. The current's westward exit from the Gulf of Alaska is known as the Alaskan Stream. A portion of the Alaskan Stream moves northward through the Aleutian passes. The distribution and intensity of flow through the Aleutian chain has been the subject of debate (Hughes et al. 1974; Reed 1971; Favorite 1974; Takenouti and Ohtani 1974; Takenouti 1976). Favorite (1974) summarized historical records of flow through the Aleutian Passes. The passes that accommodate most of the northern flow are the Amchitka Pass (1155 m depth) in the central Aleutians and the Commander-Near Strait (200 m depth) in the Commander-Near Islands. Estimates of northward flow through the Commander-Near Strait made by Favorite (1974) and Hughes et al. (1974) are 11 Sv and 25 Sv respectively (Sv indicates Sverdrups = $10^6 m^3 sec^{-1}$). Favorite (1974) estimated flow through Amchitka Pass as 4.4 Sv. Input through the eastern Aleutian group is relatively small on a yearly basis and exchange occurs in both northerly and southerly directions (Reed 1971). Takenouti and Ohtani (1974) estimated a total northward flow into the Bering Sea to be 11 Sv. While disagreeing on the magnitude of flow entering the Bering Sea there is a general agreement that this northward flow becomes part of the counterclockwise gyre in the Aleutian Basin and that most of this flow exits through the deep (4,420 m) Kamchatka Strait to the far west (Hughes et al. 1974; Takenouti and Ohtani 1974). The remaining flow moves north and exits through the Bering Strait into the Chukchi Sea. A 1.4 Sv flow through the Bering Strait was measured by Coachman and Aagaard (1966). Codispoti and Owens (1975) have employed a 1.5 Sv current for use in a silica

budget of the Arctic Ocean. The path of the northward flow from the basin over the shelf has been indicated by Natarov (in Hughes et al. 1974) as passing mostly to the east of St. Lawrence Island. The current speed in the Bering Sea is generally a few cm/sec except along the continental slope where 10-15 cm/sec have been obtained through geostrophic calculations (Takenouti and Ohtani 1974).

Hughes et al. (1974) found the wind stress field to be the primary mechanism for Bering Sea circulation from studies using drogue buoys, but they concluded that, in general, data for circulation in the Bering Sea are incomplete. Further flows are suspected to be highly variable considering the orders of magnitude of changes in winds that occur over the year (N.O.A.A. 1977).

Arsenev (1967) indicates that the shallow southeast part of the Bering Sea is separated from the deeper southwest part by a system of "transverse" currents. The location of the bar of the Transverse Current coincides approximately with the lower boundary of the eastern continental slope. Very low current velocities (5 cm/sec) are characteristic of the eastern shallows; in the bar of the Transverse Current velocities are markedly greater (around 10 cm/sec). The exceptionally low heating of the water mass in the region of the shallows is a basic result of the fact that here, over the course of the summer, the layers below 15 to 20 m are kept cold by winter water. The insulation and preservation of this cold spot over the entire warm period of the year also contributes to the character of the currents. They form, in this region, a weak but stable stationary anticyclone - - an unusual stagnant region,

practically immune to advection of heat from other sea regions. The temperature discontinuity layer in the deep-water part of the study area was at a depth of 30 to 50 m during the period studied; in the shallow water region it was at a depth of 10 to 20 m.

Data on the freshwater input via river discharge was collected and analyzed by Roden (1967). The major rivers emptying into the Bering Sea are the Anadyr and Kamchatka Rivers on the western border and the Yukon and Kuskokwim Rivers which enter on the eastern shelf.

The Yukon River, which empties into Norton Sound at a mean annual rate of 6,220 m^3sec, is the largest contributor. Yukon River flow is highly seasonal (due to snowmelt) and approximately 60% of its flow exits during June, July and August. Combined mean annual discharge of the four major rivers emptying into the Bering Sea is 9,200 m^3/sec (Roden 1967).

Ice Formation

The relationship of winds and air temperatures to the duration and southern extent of ice cover in the Bering Sea was studied by Konishi and Saito (1974) and McLain and Favorite (1976). In general, the southern ice limit is marked by the bathymetric contour of the rim of the continental slope. For most of the period from November through May, the continental shelf is covered by sea ice, most of which is formed locally (McRoy and Goering 1974). Generally, in November the ice front is located near St. Matthew Island (60°N). The front proceeds south to the continental slope and remains there during midwinter months. By June the ice front has retreated north to the vicinity of St. Lawrence Island and by July, to the Bering Strait (McRoy and Goering 1974). The intensity of cooling during winter varies from year to year

and is related to wind, temperature (McLain and Favorite 1976; Konishi and Saito 1974) and sunspot activity (Takenouti 1976). Takenouti (1976) summarized research that supported the relationship between increased sunspot activity and cooler winters in this area. The water column beneath the sea ice is vertically well mixed and water temperatures generally are within the range of -1.5 to -1.8°C.

Productivity

The Epicontinental Bering Sea is one of the most productive areas in the world (Hattori and Wada 1974). The Bering Sea supports a major commercial fishery of pollock, cod, ocean perch, black cod, halibut and rattails (Hood and Kelly 1974; Wilimovsky 1974; Alton 1974; Best 1977). The shelf area supports a large nursery for halibut and Alaskan pollock (Best 1977; Maeda and Hirakawa 1977). Total reported fish catch of the area is on the order of 10^6 metric tons of fish per year and not all countries report full catch data (Wilimovsky 1974). The yield of demersal fish per unit area in the southeastern Bering Sea exceeds that of the North Sea, Newfoundland Banks and is more than double that of Georges Bank (Alton 1974). Tanner King crab, pandalid shrimp and molluscs are commercially harvested.

Regional means of benthic biomass range from 55 g/m^2 in the southeast shelf region to 905 g/m^2 on the northern shelf (Alton 1974). In terms of demersal fish yield this food source is largely unexploited since pollock, which compose 73% of trawls, feed primarily on nektonic and nektobenthic food organisms (Alton 1974). The knowledge of fish fauna other than commercially exploited species is generally sparse (Wilimovsky 1974). According to Neiman the biomass of benthos in the Bering Sea is 250 g/m^2 on the shelf, 300-400 g/m^2 in the northwest region, 468 g/m^2 in the Anadyr Gulf, 905 g/m^2 in the Chirikov basin and 55 g/m^2 in the southeastern region. Reserves of benthos on the shelf of the Bering Sea

amount to 1,783 million centners of which 640 million centners are edible fish.

The biological driving forces at the base of the Bering Sea food chain that ultimately accommodates commercial exploitation of higher trophic levels are the primary producers: the phytoplankton and to some extent attached aquatic macrophytes (McRoy et al. 1972; Barsdate et al. 1974; McRoy and Goering 1976). The dominant phytoplankters in this area are diatoms and dinoflagellates (Marumo and Minoda 1976; Motoda and Minoda 1974). Eel grass (Zostera marina), which grows in lagoons on the perimeter of the Bering Sea (McRoy and Goering 1976), is the most important macrophyte contributing to Bering Sea production (Barsdate et al. 1974).

McRoy and Goering (1976) estimated total annual primary production in the Bering Sea to be 2.74 x 10^8 metric tons of carbon. Approximately 67% of this productivity is associated with 2.7% of the total volume of the Bering Sea which is shelf water. McRoy and Goering (1974) showed that the development of algae on the underside of sea ice is a major contributor to fixed carbon and in their budget, estimate its contribution to be 2.4 x 10^7 metric tons per year. High production rates are associated with the edge of the ice front and with the wake of the retreating ice in spring (McRoy et al. 1972; McRoy and Goering 1976). McRoy and Goering (1976) have estimated that 45% of total primary production occurs during the 60 days of spring in the Bering Sea and that only 18% is associated with the 92 days of summer in the area. However, McRoy and Goering stress that due to the lack of good spatial and temporal resolution, their production estimates should be considered as a hypothesis for future research and not a definitive description of primary production processes.

During summer, primary production rates range from 10 g C/m^2/day to several hundred mg C/m^2/day (McRoy et al. 1972; McRoy and Goering 1976; Hattori

and Wada 1974). McRoy et al. (1972), using a ^{14}C uptake method, measured 4.1 g C/m^2/day of primary production in the Bering Strait in summer, 1969. Motoda and Minoda (1974) in 1968 estimated production rates of 1.5 g C/m^2/day on a transect across the Aleutian Basin from Amchitka Pass northward to the continental slope. McRoy (1970) estimated production rates of eel grass in lagoons along the Alaskan Coast as high as 8 g C/m^2/day but the total contribution of these areas is estimated to be less than 2% of the total annual production of the Bering Sea.

Hood and Kelly (1974) concisely indicated the state of knowledge concerning processes associated with primary production in the Bering Sea:

> Despite what may appear to be a harsh climate for phytoplankton growth, the Bering Sea shelf region supports production rates that are surpassed only by upwelled regions of the world such as exist on the eastern borders of the Pacific and Atlantic Oceans. Oceanographic features of the area must provide the elements necessary for such high sustained productivity; however, the specific functions cannot be clearly defined.

The major source of nutrients to the Bering Sea is the Pacific Ocean. Upwelling at the Aleutian Passes due to the interaction of converging currents and bottom topography was reported by Kelly and Hood (1971). Other areas that are of local importance in nutrient exchange are the rivers and lagoons on the eastern coast of the Bering Sea (Hood and Beeburgh 1974).

II. METHODS AND MATERIALS

Sampling Method

A. Location of Study Area

The positions of the stations and course of the Volna are shown in Figure 2. The corresponding latitude and longitudes and sampling dates can be found in Table 1. The sampling grid was composed essentially of four transects, two running in the north to south direction and two running in a general west to east direction. The distance between stations in the northern west to east transect (N., W-E) and between stations in the southern west to east transect (S., W-E) was approximately 55 km. The distance between stations on the western north to south transect (W., N-S) and between stations in eastern north to south transect (E., N-S) was approximately 90 km. The primary stations as agreed upon in the expedition's protocol are those numbered 1 to 48 in the sampling grid. Stations 1-24 are the approximate positions of stations 25-48 respectively. The time between reoccupation of station ranged between six to eight days. Stations C1, C2 and C3 were also sampled for chlorophyll a determinations and served the expedition as "test" stations for equipment checking.

B. Meteorology (USSR)

The background material for the analysis of synoptic processes and weather along the route were meteorological charts, made on the ship for 00 h (Greenwich), surface analysis charts and baric topography received through facsimile communication links of RMC Tokyo and Pearl Harbor and data of the meteorological observations carried out on board the ship eight times per day.

1) Actinometric Observations

Actinometric observations during the cruise were conducted to observe the variation of temporal and spatial features of integral, direct, reflected and scattered solar radiation intensity.

In accordance with the program observations were started from July 17. During stormy weather, as well as while mooring, the actinometric arrow was brought on board the ship and observations were stopped. During the trip there were two moorings: from 16 to 23 July to 28 July 1977 at the port of Dutch Harbor and from 20 August to 25 August 1977 at Seattle.

Measurements of solar radiation intensity were made by standard thermoelectric instruments. Receivers of integral and reflected radiation were coated to reduce contact with water.

Receivers of radiation were located on the ship in the following way:

- direct radiation measurements were made from the upper bridge actinometer No. 268 mounted on cardanic suspension;

- pyranometer No. 1268 (solarigraph) and pyranometer No. 2900 (recorder of reflected radiation) were mounted at actinometric arrow with cardanic suspension. The height of instruments above the surface of the water was 10 m, the distance from the ship's bow was -10 m;

- the receiver of solar scattered radiation (pyranometer No.1065 and No. 1005 from August 2) was mounted on the upper bridge at a height of 13m above the water surface on cardanic suspension. Potentiometer 3MM-09 was used for measurements of solar radiation intensity;

- integral, reflected and scattered radiation were recorded on ЭМИ-09 No. 7837 with scale 2 mv with a tape transport speed 6.

The record of direct solar activity was made by potentiometer ЭМИ-09 No. 7838 with 2 mv scale with a tape transport speed 50 cm/h.

C. Atmospheric Chemistry (USSR)

1) Radioactive Nuclides

Atmospheric aerosol samples for analysis of radionuclide (Pb^{212} Pb^{214}) content were obtained by pumping large volumes of air through an acetyl cellulose filter (FPP-15) with a cross section of 0.5 m^2. A blower producing 25± m^3/min was set up on the upper bridge and run without interruption throughout a 24-hour period. The filters were changed every six hours.

After the aerosol sampling was complete, the acetyl cellulose filter layer was carefully separated from the gauze base, turned so that its working surface was inside, and placed in a press 49 mm in diameter under a pressure of 150 atm. This produced a brickette 49 mm in diameter and 10 mm thick, which was then analyzed in a spectrometer.

The natural radionuclides Pb^{214} were determined through the use of a gamma spectrometer. The scintillation gamma spectrometer consisted of a USD-1 detector with an NaI(Tl) crystal measuring 40 mm in diameter by 40 mm and a 4-128-P 128-channel type A impulse analyzer. The data were read out on a digital printer attached to the analyzer and EPP-09 recorder.

To determine Pb^{214} the sample was measured immediately after sampling was completed. The sample was exposed on the spectrometer for 20 minutes. Pb^{214} was identified and calculated on the basis of the full absorption peak of 609 kev gamma quanta. The concentration of Pb^{214} in the layer of atmosphere

adjacent to the water at the moment when sampling was completed was computed in curies/liter by the formula:

$$q_{Pb^{214}} = \frac{N_{609} \cdot \lambda_2 (\lambda_1 - \lambda_2)}{2.22 \cdot 10^{15} \cdot KY^{609} \cdot \varepsilon_L^{609} (\lambda_2 e^{-\lambda_2 t_o} - \lambda_2 e^{-\lambda_1 t_o}) \cdot v}$$

where N_{609} = the amplitude of the E_y = 609 kev peak (imp/min);

λ_1 and λ_2 = the decay constants of Pb^{214} and Bi^{214}, equalling

$\lambda_1 = 2.59 \cdot 10^{-2} min^{-1}$ and

$\lambda_2 = 3.52 \cdot 10^{-2} min^{-1}$ respectively;

K_y = the effective quantum output of 609 kev gamma quanta in the decay of Bi^{214} (K_y = 0.33);

ε_L^{609} = the amplitude effectiveness of detection of 609 kev gamma quanta in the given geometry ($\varepsilon_L^{609} = 4 \cdot 10^{-3}$);

v = the volume velocity of air pumped through the filter (m^3/min);

t_o = the time elapsed from the completion of sampling to the mid-point of exposure of the sample in the gamma spectrometer (min).

To determine Pb^{212} the sample was measured 6-10 hours after sampling was completed, i.e. after the short-lived nuclides Pb^{214}, Bi^{214} etc. had decayed. The sample was exposed on the spectrometer for 20 minutes. Pb^{212} was identified and calculated on the basis of the full absorption peak of 239 kev gamma quanta. The concentration of Pb^{212} in the layer of atmosphere adjacent to the water at the moment when sampling was completed was computed in curies/liter by the formula:

$$q_{Pb^{212}} = \frac{N_{239} \cdot \lambda \cdot e^{\lambda t}}{\varepsilon_L^{239} \cdot K_\gamma^{239} \cdot v \cdot 2.22 \cdot 10^{15} (1 - e^{-\lambda t})}$$

where N_{239} = the amplitude of the E_γ = 239 kev peak (imp/min);

λ = the decay constant of Pb^{212}

($\lambda = 1.09 \cdot 10^{-3} min^{-1}$);

t = the time elapsed from the completion of sampling to the midpoint of exposure of the sample in the gamma spectrometer;

ε_L^{239} = the amplitude effectiveness of detection of 239 kev gamma quanta in the given measurement geometry

($\varepsilon_L^{239} = 2.6 \cdot 10^{-2}$);

K_γ^{239} = the quantum output of 239 kev gamma quanta in the decay of Pb^{212}($K_\gamma^{239} = 0.47$);

t = the sampling time (min).

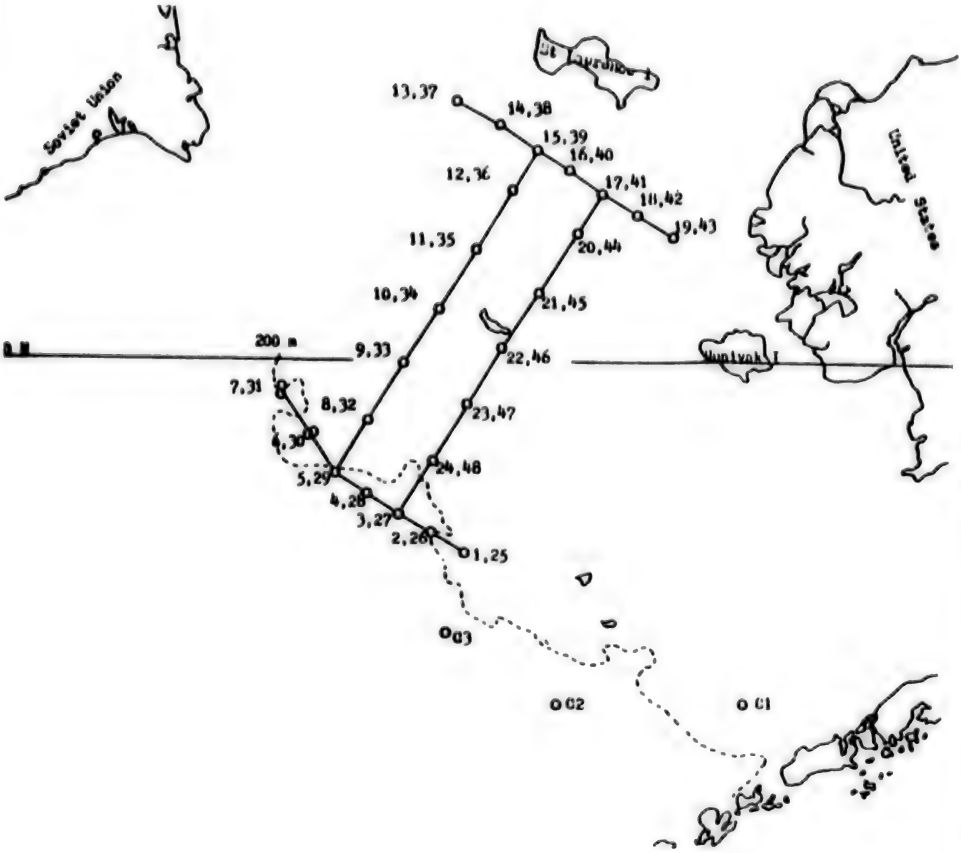

Figure 2. Location of stations and station labeling.

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Table 1

Positions, Sampling Dates and Depth of Stations of the Bering Sea Expedition, 1977

STA*	STA**	POSITION*	POSITION**	DATE*	DATE**	DEPTH* (m)	DEPTH** (m)
C1		55°30'N 166°00'W		7-29-77		125	
C2		55°30'N 170°50'W		7-29=77		3365	
C3		56°25'N 173°45'W		7-30-77		2580	
1	25	57°30'N 173°20'W	Same	7-30-77	8-06-77	125	123
2	26	57°45'N 174°10'W	Same	7-31-77	8-06-77	144	110
3	27	57°59'N 175°00'W	Same	7-31-77	8-06-77	2700	2630
4	28	58°30'N 175°50'W	58°15'N 175°50'W	7-31-77	8-07-77	2700	2700
5	29	58°30'N 176°40'W	Same	7-31-77	8-08-77	1140	1140
6	30	59°00'N 177°25'W	59°01'N 177°18'W	8-01-77	8-08-77	130	140
7	31	59°35'N 178°10'N	59°30'N 178°10'W	8-01-77	8-08-77	225	220
8	32	59°12'N 175°48'W	Same	8-01-77	8-09-77	140	137
9	33	59°55'N 174°56'W	Same	8-01-77	8-09-77	115	119
10	34	60°37'N 174°12'W	60°37'N 174°05'W	8-02-77	8-09-77	90	85
11	35	61°20'N 173°12'W	Same	8-02-77	8-09-77	70	70
12	36	62°02'N 172°17'W	Same	8-02-77	8-09-77	58	58

* First Sampling

** Second Sampling

Table 1 - continued

STA*	STA**	POSITION	POSITION**	DATE*	DATE**	DEPTH* (m)	DEPTH** (m)
13	37	63°00'N 173°40'E	Same	8-03-77	8-10-77	70	70
14	38	62°45'N 172°40'W	Same	8-03-77	8-10-77	57	57
15	39	62°30'N 172°40'W	Same	8-03-77	8-10-77	50	49
16	40	62°15'N 170°50'W	Same	8-03-77	8-10-77	45	41
17	41	62°00'N 170°00'W	Same	8-04-77	8-10-77	44	44
18	42	61°45'N 169°05'W	Same	8-04-77	8-10-77	37	38
19	43	61°30'N 168°10'W	Same	8-04-77	8-11-77	29	29
20	44	61°35'N 170°35'W	Same	8-05-77	8-11-77	49	48
21	45	60°49'N 171°32'W	Same	8-05-77	8-11-77	62	60
22	46	60°06'N 172°28'W	Same	8-05-77	8-12-77	58	58
23	47	59°25'N 173°21'W	Same	8-05-77	8-12-77	100	100
24	48	58°41'N 174°10'W	Same	8-06-77	8-12-77	140	139

* First Sampling

** Second Sampling

2) Sulfur Dioxide

The sample-taking arrangement for SO_2 was comprised of bubble-type gas absorbers with absorbing solutions or sorption tubes (packed columns) and microcompressors with a volume rate of flow of approximately 5 l./min. This system was also mounted on the bow of the ship. The construction of the wind vane, which was mounted on an iron stand, permitted the air-intake devices to be operating only when the direction of the wind was within $\pm 60^{\circ}$ from a headwind. If the wind direction was across the beam or abaft, the wind vane would close the air-intake devices through electronic connections.

The sampling period for each sample of air sampled for sulfur dioxide, trace metals and hydrocarbons was approximately two days, in the course of which the air passed through the filters amounted to a volume of approximately 2500 m^3, and that passed through the bubble-type absorbers and/or sorption tubes was greater than 1 m^3.

Sulfur dioxide was sampled by two different methods. In one case it was done by bubbling the air sample to be analyzed through a solution of disodium tetrachloromercurate, and in the other by absorbing the SO_2 on the surface of a solid sorbent, the granules of which were wetted with a glycerin solution of disodium tetrachloromercurate. There were a number of advantages to taking of the sample of sulfur dioxide on the solid sorbent; for example, a two to threefold increase in the volume filtered was possible, with the concomitant shortening of the exposure time. However, in worldwide practice

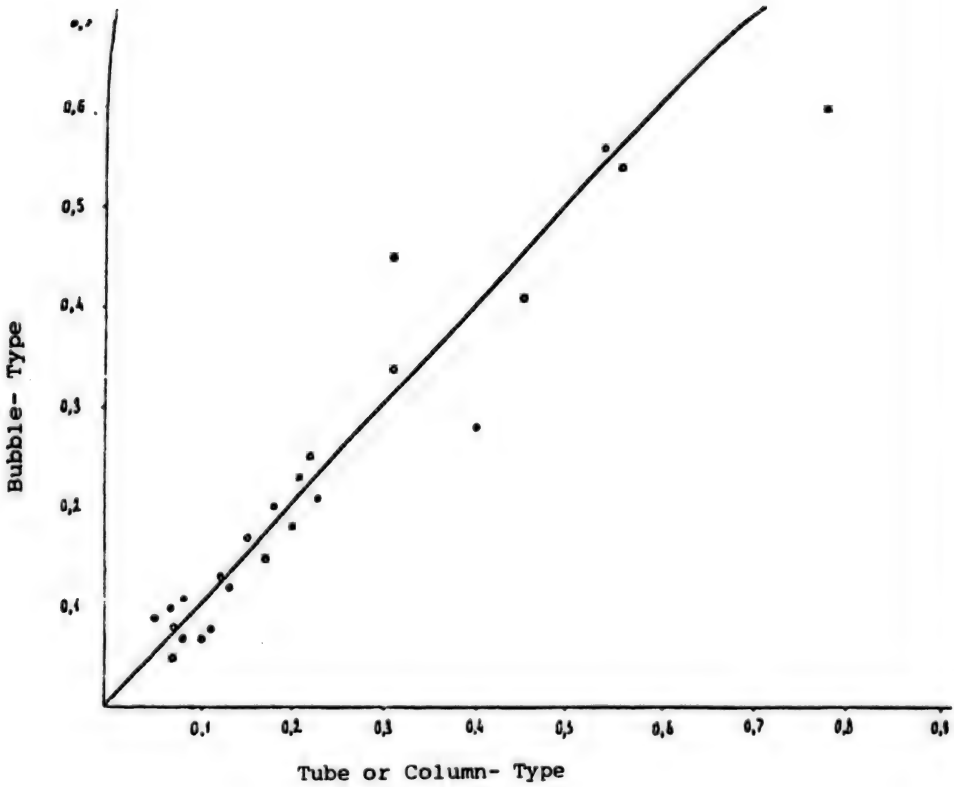

Figure 3. Relation between concentrations determined by two methods.

there is a lack of experience in determining background concentrations using solid sorbent and one of the tasks which was worked on during the expedition was the development of a method of sampling onto a solid sorbent in regions of clean atmosphere, and a comparison of the two sampling methods. Over the course of the expedition, 26 parallel samples were taken using the above-mentioned methods of sample-taking. The results of the determinations are shown in Fig. 3 in graphic form, showing the correlation of the concentration values determined by the two methods. As seen from this figure, the results from both sample-taking methods were similar, and the scatter in the data was considered to be insignificant.

Specially designed experiments showed that the pass through of sulfur dioxide was virtually zero when the rate of flow of air through the absorber was on the order of 5.0 liters per minute, with a total throughput of up to 2 m^3. This result permitted taking sulfur dioxide samples with two absorbers connected sequentially, with the sample from the second absorber used as the "null" sample in the determination of differences in optical densities. This method made it possible to exclude the possibility of errors connected with the effects of external factors on the absorber, particularly in the event of an extended exposure time, since in this case the "working" and "null" samples would be operating under identical conditions for the entire period of exposure, and would be subject to the effects of external factors to an equal degree.

The analysis of the samples was carried out by the modified method of West and Geike (1956), using an SF-16 spectrophotometer at a wavelength of 545 nm. The sensitivity limit for the determination was evaluated as an amount of SO_2 of 0.2 microgram per sample, which, assuming a sample of 1 m^3 of air, corresponds to a concentration of 0.04 microgram/m^3.

Trace Metals

As indicated the sampling system was mounted on the bow of the ship. The sampling period was approximately two days, and the total volume of air filtered was approximately 2500 m^3. The filters were made of acetyl cellulose (FPA-15) with a surface area of 250 cm^2. The volume flow rate of the blower was approximately 100 m^3/hr.

Filters F1-F7 were used to determine the content of metals in the air. These filters were calcined in a muffle furnace at 450°C for 5-6 hours until a grey or brown powder was formed. After each calcining the porcelain crucibles were treated with a mixture of hydrofluoric and nitric acid at around 200°C to remove residues of the sample. After calcining a suspension of the ashes with an accuracy of 0.1 mg was produced in order to determine the total metal content.

The ashes were dissolved in teflon dishes which were placed on a rocker and heated. Two to three ml of a high purity 2:1 hydfluoric nitric acid mixture was poured onto the ashes. After the solution evaporated, 2 ml more of the acid mixture was added and this procedure was repeated 3-4 times until the ashes were completely dissolved, after which 10-15 ml of double-distilled water was added. This acidified solution was poured into a pyrex glass test tube for subsequent analysis for metals.

Preliminary studies had shown that when the filters are calcined and passed into solution, no more than 5% of an introduced quantity of the metals under study was volatilized. An exception is cadmium, the loss of which during

Table 2

Trace Metal Content of FPA-15 Filters*

Metals (ng/cm^2)

Cd	Cu	Fe	Mg	Ni	Pb	Zn
N.D.**	2	80	20	8	0.05	15

* filter Ash-0.7 ug/cm^2

** N.D. - not detected

all the operations described above totals approximately 70%. This value was taken into account in calculating the cadmium content of the air.

Copper, zinc, lead, cadmium, nickel, iron and magnesium were determined in the samples by the method of atomic absorption (Jarrell Ash AA-780). Careful attention was paid to the content of the determined elements in the filters and in the reagents. The background in the FPA-15 filters was determined by ashing three filters with an area of 0.5 m^2 each, and transferring the ashes to separate acid solutions. The average background of the FPA-15 filters/cm^2 is shown in Table 2 .

4) Hydrocarbons

Samples of atmospheric aerosols to determine hydrocarbon content were taken on FPA acetyl cellulose filters with a cross section of around 250 cm^2. All filters were first cleaned for seven hours with high-purity carbon tetrachloride in a Soxhlet apparatus. The filters were then dried between sheets of pre-cleaned filter paper, and stored in polyethylene packets until they were placed in the air intake device.

After sampling, the filter was placed in a Soxhlet apparatus for extraction with 130 ml of high-purity carbon tetrachloride for five hours. The extract was then concentrated by evaporation in a water bath to a volume of 10 ml and under a fan to a volume of 1 ml. This volume was then passed through a chromatograph column containing aluminum oxide to separate polar and nonpolar compounds. Qualitative determination of hydrocarbon content was

carried out aboard ship using an LKhM-8 MD chromatograph. The hydrocarbons were separated with a steel fractionating column 1.8 m long and 3 mm in diameter filled with Chromosorb W sorbent and 5% SE-30. The analysis was carried out in a flame-type ionization detector with a programmed temperature from 100°C to 290°C and a rate of temperature change of 6°/min. High purity nitrogen was used as the carrier gas. The rate of nitrogen flow was 30 ml/min, the rate of hydrogen flow 30 ml/min, and the rate of air flow to the detector 300 ml/min.

The above gas chromatograph analyses were supplemented in the on-shore laboratory by the determination of the total hydrocarbon content in the extracts. The volume of the extract was increased to 5 ml by the addition of purified carbon tetrachloride and the extract was measured on an IKS-24 infrared spectrometer in the wavelength region of 2800-3100 cm^{-1}. The sensitivity of measurement of total hydrocarbon content on the infrared spectrometer was 0.05 mg/sample.

For evaluating the possible background contamination of the filters and of the carbon tetrachloride, filters which had not been exposed but had been extracted one time were subjected to a second extraction in a Soxhlet apparatus for three hours. They were then further treated as described above: i.e. the extract was evaporated to 1 milliliter, passed through a chromatographic column containing aluminum oxide, and subjected to semiquantitative determination, i.e. on the chromatograph as well as determination of total hydrocarbons on the infrared spectrometer. The background content was $(3 \pm 1) \times 10^{-4}$ g per filter, based on the three filters. This value was subsequently taken into account in calculating the concentrations of hydrocarbons in the atmosphere.

5) Benzo(a)pyrene

After aerosol samples were taken, two filters (F4 and F5) were packed in polyethylene packets for on-shore determination of the content of benzo(a)pyrene (BP) a carcinogenic hydrocarbon. In the on-shore laboratory the extraction of these filters was carried out through the use of benzene in a Soxhlet apparatus. These extracts were concentrated by evaporation in a water bath to a volume of 5 ml and the polycyclic aromatic hydrocarbons were separated by thin-layer chromatography on a 20 x 20 cm plate in a thin layer (1 mm) of aluminum oxide. The separated fraction was subjected to qualitative and quantitative spectral analysis and BP distinguished by the intense 403.0 nm line in its fluorescence spectrum. A quartz test tube containing the extract was immersed in a clear quartz Dewar flask containing liquid nitrogen. A quartz condenser was used to focus excitation illumination on the extract-containing test tube. A quartz condenser also focussed the luminescence light on the spectrometer slit.

To identify and quantitatively determine BP by its fluorescence spectrum, the spectrum of each extract was recorded on a DFS-12 spectrometer. A DRSh-50 mercury quartz lamp with an UFS-2 light filter served as the excitation source. The admixture method was used to determine BP quantitatively. The error for determining BP by this method is ± 10%. The sensitivity of this method is 10^{-10}g.

A detailed description of the technology and methodology for determining polycyclic aromatic hydrocarbons by their quasiline luminescence spectra is found in Shpolskiy et al. 1952., Gayevaya and Khesina 1974., Varshavskiy et al. 1965., and Khesina and Petrova 1973.

D. Hydrologic

(1) Physical

(a) USSR Methods

Salinity

Samples of sea water were collected from the bathometer (after sampling for dissolved oxygen and pH) through a rubber tube into various 100-250 ml flasks with close fitting rubber stoppers. After the samples were taken the flasks were rinsed 2-3 times with water from the bathometer and then filled with water, but not completely up to the stopper in order to avoid sample loss due to changes of temperature. Titration of the sea water samples was undertaken after they had assumed laboratory temperature. For this purpose they were kept in the laboratory for at least an hour.

The method of determining salinity was based on finding the chlorinity of the sea water (Cl‰), which is taken to mean the total amount in grams of halides (chlorides, bromides and iodides, but excluding fluorides) contained in 1 kg of sea water, converted to equivalent chloride content. The salinity was determined by titration of the sea water sample with a silver nitrate ($AgNO_3$) solution to complete precipitation of all halides, except fluorides. The absolute mean systematic error of the method is 0.01‰.

Salinity was determined by the methods described in the Handbook of Methods for the Chemical Analysis of Sea Water (1977).

Deep-water thermometers (TG) with an accuracy of 1/100° were used to determine the temperature of the sea water.

Determination of dissolved oxygen. The sample taken for determination of dissolved oxygen was the first removed from the bathometer. For this purpose

after an oxygen flask and rubber tube had been rinsed with water from the bathometer, a glass tube 10 cm long was inserted into the end of the rubber tube and lowered into the bottom of the oxygen flask. The water was poured in at a moderate rate to avoid air bubbles and one flaskful was decanted through the throat of the flask after filling. Without closing the stopcock of the bathometer, the tube was carefully removed from the flask and only then was the stopcock closed. The flask was filled to the brim and had no air bubbles on the sides.

Immediately after filling the dissolved oxygen was fixed for which purpose 1 ml of manganese chloride (or manganese sulfate) solution and 1 ml of potassium iodide (or sodium iodide) solution were introduced into the flask in succession.

Pipettes containing these reagents were lowered to half the height of the flask. After the reagents were introduced the flask was carefully stoppered, avoiding the introduction of air bubbles, and the resultant precipitate vigorously mixed by briefly inverting the flask 15-20 times until the precipitate was evenly distributed in the water. The flasks with the fixed samples were then transferred to a warm place for settling. They were kept in this condition a maximum of 24 hours at a temperature $< 10^{o}C$ and no more than four hours at higher temperature.

Titration of samples with fixed oxygen was begun only when the settled precipitate occupied less than half the height of the oxygen flask. The method of analysis was based on the oxidation of bivalent manganese to a

water-insoluble brown hydrate of quadrivalent manganese, which in an acid medium liberates free iodine which can be quantitatively determined by use of a titrated solution of sodium hyposulfite. The minimum concentration determinable by this method is 0.06 ml/l with an accuracy of ± 0.02 ml/l.

Dissolved oxygen was determined by the method described in the Handbook of Methods of Chemical Analysis of Sea Water (1977).

One of the main goal of the USA/USSR research during the first expeditional trip of scientific-research ship (SRS) "Volna" was calibration of Soviet and American methods of water analysis.

Fig. 4 presents a correlation plot of the relation of water temperature values obtained by American and Soviet scientists. Observations of water temperature were carried out by a hydrological team of SRS "Volna" with the help of deep-water reversing thermometers. The Americans used hydroprobes and bathometers "Niskina" with deep-water thermometer made in Japan. Temperature differences at all stations did not exceed 0.2°C. In the near bottom layers at stations carried out in the region of shelf zone the temperatures were similar. The greatest differences in water temperatures of Soviet and American measurements were at the upper limits. The reason for this is in the fact that while processing the data it is not possible to determine the thermocline start with the accuracy of 1 m whereas the hydroprobe allowed us to do it.

In general American and Soviet data on temperature can be compared without introduction of corrections.

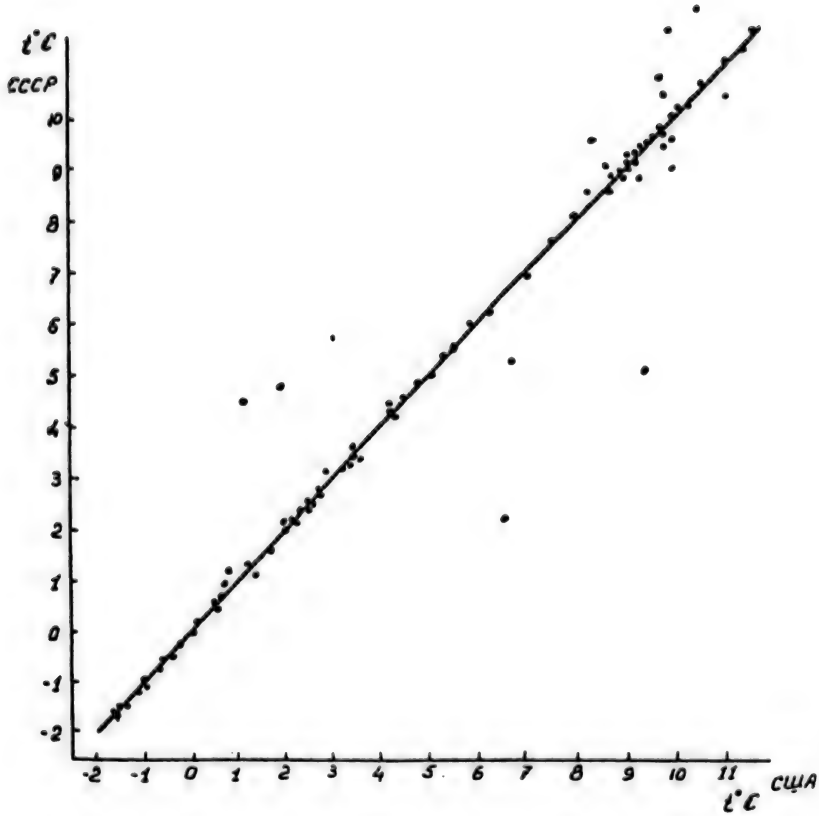

Figure 4. Correlation between USA-USSR thermometric data.

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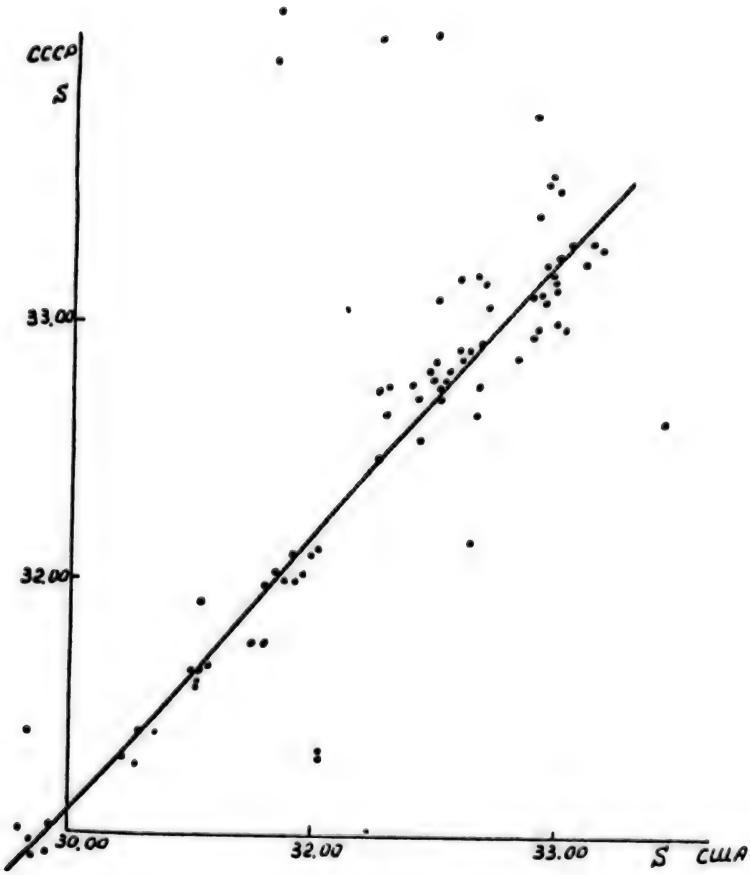

Figure 5. Correlation between USA-USSR salinity data.

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Fig. 5 presents a plot of salinity values obtained at each station. Data analysis showed that the salinity data are somewhat different and American values, as a rule, are lower than the Soviet values. The greatest difference, as for water temperature, was noted with high values of salinity, the calibration correction decreased with the decrease of absolute values. The correction value for Arerican data of salinity values is:

USSR	USA	Diff
33.00	- 32.78	+ 0.22
32.90	- 32.69	+ 0.21
32.80	- 32.60	+ 0.20
32.70	- 32.51	+ 0.19
32.60	- 32.42	+ 0.18
32.50	- 32.33	+ 0.17
32.40	- 32.24	+ 0.16
32.30	- 32.14	+ 0.16
32.20	- 32.04	+ 0.16
32.10	- 31.95	+ 0.15
32.00	- 31.85	+ 0.15
31.90	- 31.76	+ 0.14
31.80	- 31.67	+ 0.13
31.60	- 31.48	+ 0.12
31.50	- 31.39	+ 0.11
31.40	- 31.30	+ 0.10
31.30	- 31.21	+ 0.09

At some stations the differences were greater and the precise reasons for this have not, as yet, been established.

(b) USA Methods

Temperature, Salinity and Light

A multiparameter Interocean System 513D submersible probe was used for vertical profiling of temperature, salinity, downwelling, irradiance and depth on station. The probe was automated to obtain information at discrete depths while being lowered through the water column. The sampling resolution was approximately one reading per meter and was a function of the probe's rate of descent. The scanning frequency of the system remained constant at 0.25 scan/second. A description of the automating procedure is included as an appendix to this paper. The water column was profiled to a maximum depth of 75 meters and to several meters above bottom at shallower stations.

The Interocean 513D probe package contains two temperature sensors; one is a highly conductive platinum probe which provided the temperature records, the other sensor's output was combined with the output of the conductivity sensor to generate salinity data. Temperatures recorded by the platinum probe were regularly checked using reversing thermometers attached to Niskin bottles. The platinum sensor records were combined with conductivity data to recalculate salinities by the method of Accerboni and Mosetti (1967). The precision of the sensors as specified by Interocean Systems Ltd., San Diego, California is $\pm$ .02 millimhos for conductivity, $\pm$ .02°C for temperature, $\pm$ .05 ppt for salinity and $\pm$ 3 m for depth.

Total visible, "red", "blue", and "green" downwelling irradiance was measured with photocells and filters from an Interocean System 510 Illuminance

System. The filter specifications pertaining to the distribution of passing wavelengths have been requested from the Hoya Corporation, Tokyo, Japan and are not presently available. Voltages from the submarine photocell and deck photocell were non-linear with irradiance (measured as foot-candles) and were converted to foot-candles using a formula determined from at least squares fit of recalibration voltage and foot-candle data. Extinction coefficients were calculated as the slope of the linear transformation of the Beer Lambert Law by least squares fitting (Harvey 1963).

$$\ln I_z = K_e \cdot Z + \ln I_o \qquad (1)$$

where

- z - depth (meter)
- I_o - downwelling irradiance at the surface (ft -c)
- I_z - downwelling irradiance at depth Z (ft -c)
- K_e - extinction coefficient (meter^{-1})

Calculations were done using an IBM 5100 computer compiled in APL. The agreement of observed with the regression equation was judged to be not acceptable below .16 volts which correspondsto intensity readings of 8 ft - c thus lower readings were omitted from calculations of extinction coefficients.

(c) Chemical

1) Water

Seawater samples for the expedition were collected with a bathometer (USSR) and an Interocean System submersible pump and a Niskin Rosette Sampler (USA).

Samples were collected at depths of 1, 10, 25, 50, 75 and approximately 5 m from the bottom at stations having depth 80 m in depth.

a) Nutrients

1) USSR

a) Phosphates

A sampling flask was filled with sea water from the bathometer after the flask and stopper had been rinsed twice with sea water. The reagents were then added and the flasks were transferred to the laboratory and allowed to stand for some time until they reached room temperature. The analysis of these samples took place no later than six hours after sampling since keeping them for a longer time may lead to the decomposition of the organic matter of plankton and the transformation of organic phosphorus into mineral phosphorus, producing significant errors in the results.

At present the Murphy and Riley (1964) method of determining phosphorus, which uses ascorbic acid as a reducing agent, has been adopted in many countries in accordance with the recommendations of the International Ocean Research Council. Calcium antimonous tartrate is used as a catalyst to accelerate the reaction. The mean relative error does not exceed $\pm$ 1.1%.

A detailed description of the methodology is found in S. Oradovskiy (1977).

b) Nitrides

Samples of sea water for determining nitrides are taken in flasks with ground glass or rubber stoppers which had been first washed twice with the

same water. These samples were quite stable at room temperature, although the analysis must be done 5-10 hours after the sample is taken. If the fresh sea water samples contain many suspended particles, they should be filtered.

Nitrites were determined by the Grissilosvay method, which is based on the diazotization of nitrites contained in sea water by sulfanilic acid through the subsequent reaction of the resulting diazo compounds with a-napthalene, causing the appearance of a red azo dye. Five ml of Griss-illosvay reagent was added to a retort or Nessler cylinder with a ground glass stopper. The solution was carefully mixed and after one hour its optical density was measured on an FEK-56 M with a 50 mm long vessel fitted with a No. 6 light filter facing the vessel and containing nitrite-free sea water to which Grissilovsay reagent had also been added.

Based on the observed optical density value, the concentration of nitrite nitrogen in the sea water sample (in ug/l) is read from a calibration chart.

A detailed description of the methodology is set forth in Handbook of Methods of Chemical Analysis of Sea Water (1977).

2) USA

a) Nutrients

Samples were collected with an Interocean Systems submersible pump at the surface (one meter), 10, 25, 50 and 75 m. Samples were taken approximately 5 meters from the bottom for station with depths greater than 80 m.

Phosphate, ammonia, nitrite, nitrate and soluble silicates analyses were performed on board ship, usually within three hours of collection, using Technicon AAII and Aqualyzer auto analyzers and Technicon colorimetric methodology (Technicon Industrial Systems 1972, 1973a, 1973b, 1973c, 1976; Armstrong et al 1967). The Technicon PO_4 method, a modification of the method originally devised by Murphy and Riley (1964), uses a single reagent acidified solution of ammonium molybdate containing ascorbic acid and antimony to form the phosphomolybdenum blue complex which is then read colorimetrically at 880 nm. The detection limit of this method is .08 ug-at P/l.

The NO_2 analysis method exploits the reaction of the nitrite under acidic conditions with sulfanilamide to yield a diazo compound which couples with N-1-naphthylethylene-diamine dihydrochloride to form a soluble dye. This method is capable of detecting nitrite at .04 ug-at N/l. Nitrate analysis involves the reduction of nitrate to nitrite in a copper cadmium column. The resulting nitrite concentration is then measured as above. The method for NH_3 analysis reacts a formed ammonium salt with sodium phenoxide followed by sodium hypochlorite to form a blue compound believed to be related to indophenol. The detection limit for this method is 0.2 ug-at N/l.

The method for analysis of Si as silicates uses the formation of silicomolybdate and its subsequent reduction in acidic solution to molybdenum blue by ascorbic acid. The detection limit of the method is 1.0 ug-at Si/l.

In the course of the activity at the test-site simultaneous observations were carried out by American and Soviet specialists. Oxygen,

Table 3

Comparison of Data Collected by American and Soviet Scientists in the Bering Sea

		USA	USSR		USA	USSR		USA			USSR		
I	2	3	4	5	6	7	8	9	10	11	12	13	14
I	0	8.27	8.28	-0.01	7.65	6.93	0.72	2.7	0.66	2.04	10.0	9.43	0.57
	10	8.26	8.25	0.01	7.73	7.08	0.65	2.7	0.66	2.04	12.8	9.00	3.8
	25	8.22	8.18	0.04	8.07	7.23	0.84	3.4	0.79	2.61	21.0	12.2	8.8
	50	8.04	8.01	0.03	7.00	6.70	0.30	4.6	1.45	3.15	41.0	39.80	1.2
	75	7.97	7.90	0.07	6.32	6.12	0.20	5.3	1.78	3.56	57.0	54.4	2.6
2	0	8.24	8.12	0.12	7.47	7.03	0.44	2.2	0.95	1.25	6.0	6.27	-0.27
	10	8.24	8.19	0.05	7.54	6.03	1.51	3.2	1.06	2.14	16.0	6.27	9.73
	25	8.23	8.22	0.01	7.81	7.46	0.35	3.8	1.20	2.60	19.0	9.57	9.43
	50	8.16	8.15	0.01	8.08	6.94	1.14	4.8	1.28	3.52	57.0	25.1	31.9
	75	8.01	8.05	0.04	6.89	6.17	0.72	5.2	1.70	3.50	61.0	44.0	17.0
3	0	8.25	8.19	0.06	7.40	6.95	0.45	1.7	0.66	1.04	2.5	7.3	-4.8
	10	8.27	8.24	0.03	7.42	7.25	0.17	1.6	0.58	1.02	1.5	6.8	-5.3
	25	8.29	8.29	0.00	7.85	7.59	0.26	1.8	0.54	1.26	2.2	9.4	-7.2
	50	8.18	8.29	-0.11	0.07	7.55	-7.48	3.0	0.82	2.18	12.6	12.6	0.0
	75	8.06	7.92	0.14	7.24	6.96	0.28	4.2	1.54	2.66	31.0	27.2	3.8

Table 3 continued

1	2	USA 3	USSR 4	5	USA 6	USSR 7	8	USA 9	10	11	USSR 12	13	14
4	0	8.25	8.35	-0.10	7.04	6.93	0.11	2.10	0.79	1.31	2.3	6.3	-4.0
	10	8.26	8.36	-0.10	7.08	7.05	0.03	2.0	0.80	1.20	3.1	6.3	-3.2
	25	8.26	8.36	-0.10	7.26	7.17	0.09	2.1	0.98	1.12	4.3	14.3	-10.0
	50	8.08	8.23	-0.15	7.50	7.16	0.34	4.0	1.78	2.22	34.5	41.9	- 7.4
	75	7.98	8.09	-0.11	6.60	6.82	-0.22	4.4	2.06	2.34	51.0	52.4	- 1.4
5	0	8.33	8.31	0.02	7.08	7.11	-0.03	1.6	0.66	0.94	5.0	6.27	- 1.27
	10	8.31	8.32	-0.01	7.02	7.10	-0.08	1.8	0.80	1.00	4.0	7.3	- 3.3
	25	8.24	8.10	-0.14	7.31	7.00	0.31	3.1	1.06	2.04	15.0	17.1	- 2.1
	50	8.06	8.13	-0.07	6.88	6.60	0.28	4.4	1.61	2.79	33.5	44.0	-10.5
	75	7.97	8.07	-0.10	6.00	6.46	-0.46	4.6	1.98	2.62	44.0	54.4	-10.4
6	0	8.41	8.28	-0.13	6.97	7.02	-0.05	0.60	0.49	0.11	1.7	7.3	- 5.6
	10	8.42	8.37	-0.05	6.95	6.95	0.00	0.30	0.66	-0.36	5.0	6.3	- 1.3
	25	8.40	8.38	-0.02	7.86	7.86	0.00	1.2	1.70	-0.50	5.5	14.6	- 9.1
	50	8.06	8.13	-0.07	7.30	7.18	0.12	4.6	2.43	2.17	36.0	37.7	- 1.7
	75	7.98	8.03	-0.05	6.49	6.75	0.26	5.1	2.57	2.53	54.0	56.5	- 2.5
7	0	8.35	8.18	0.17	7.11	7.15	-0.04	1.3	0.63	0.67	1.0	6.3	- 5.3
	10	8.36	8.33	0.03	7.19	7.27	-0.08	1.2	0.82	0.38	1.0	10.9	- 9.9
	25	8.36	8.34	0.02	7.54	7.60	-0.06	1.5	1.28	0.22	2.0	17.8	-15.8
	50	8.06	8.14	-0.08	7.04	7.45	-0.41	4.1	1.94	2.16	33.0	41.9	- 8.9
	75	8.03	8.10	-0.07	6.72	7.24	-0.52	4.4	1.94	2.46	72.0	62.8	- 9.2

Table 3 continued

1	2	USA 3	USSR 4	5	USA 6	USSR 7	8	USA 9	10	11	USSR 12	13	14
8	0			0.15	6.	7.03	-0.11	2.5	0.33	2.17	3.0	6.1	- 3.1
	10	8.40	8.36	0.04	6.95	7.22	-0.27	2.5	0.33	2.17	3.0	6.1	- 3.1
	25	8.42	8.32	0.10	7.08	7.44	-0.36	3.0	1.62	1.38	3.0	10.0	- 7.0
	50	8.11	8.12	-0.01	7.44	6.04	1.40	-	2.24	-	36.0	20.7	15.3
	75	7.97	7.98	-0.01	6.29	6.12	0.17	3.1	2.34	0.76	84.0	60.7	23.3
9	0	8.47	8.32	-0.15	6.99	7.13	-0.14	1.1	0.49	0.61	6.5	8.4	- 1.9
	10	8.49	8.48	-0.01	6.99	7.19	-0.20	1.0	0.49	0.51	7.0	8.4	- 1.4
	25	8.43	8.38	0.05	8.31	7.68	0.63	0.80	1.20	-0.40	7.0	18.8	-11.8
	50	8.02	8.03	-0.01	7.00	6.89	0.11	2.5	2.43	0.07	56.0	49.2	- 6.8
	75	7.95	8.05	-0.10	6.24	7.04	0.80	2.9	2.47	0.43	83.0	49.2	33.8
10	0	8.39	8.23	0.16	6.88	6.93	-0.05	1.0	0.16	0.84	0.5	4.4	- 3.9
	10	8.40	8.40	0.00	6.89	6.98	-0.09	0.10	0.16	-0.06	0.5	4.2	- 3.7
	25	8.48	8.40	0.08	7.65	8.36	0.71	1.0	0.42	0.58	5.3	16.8	-11.5
	50	8.06	8.13	0.07	6.91	7.45	-0.54	3.6	1.12	2.48	10.5	20.9	-10.4
	75	8.04	8.13	-0.09	6.65	7.50	-0.85	4.1	1.28	2.82	12.5	22.8	-10.3

Table 3 continued

1	2	USA 3	USSR 4	5	USA 6	USSR 7	8	USA 9	10	11	USSR 12	13	14
11	0	8.20	8.33	-0.13	6.99	7.03	-0.04	0.90	0.33	0.57	1.4	6.3	- 4.9
	10	8.00	8.48	-0.48	7.03	7.08	-0.05	0.80	0.33	0.47	1.2	8.4	-7.2
	25	8.10	8.33	-0.23	8.36	8.44	-0.08	1.0	0.68	0.32	1.1	9.4	- 8.3
	50	7.54	7.95	-0.41	6.59	6.70	-0.11	3.7	0.95	2.75	11.5	18.8	- 7.3
	75(60)	7.51	7.92	-0.41	6.22	6.93	-0.71	3.9			13.5	25.1	-11.6
12	0	8.07	8.27	-0.20	7.05	7.23	-0.18	1.30	0.49	0.81	0.50	6.3	- 5.80
	10	8.07	8.41	-0.34	7.05	7.17	-0.12	1.30	0.82	0.48	0.50	6.3	- 5.80
	25	7.84	8.24	-0.40	8.74	9.30	-0.56	2.70	1.00	1.70	5.50	14.7	- 9.20
	50	7.65	8.00	-0.35	7.21	7.74	-0.53	3.10	1.12	1.98	6.00	18.0	-12.0
	75												
13	0	13.27	8.22	5.05	7.38	7.34	0.04	1.40	0.53	0.87	3.50	6.3	- 2.80
	10	13.23	8.46	4.77	7.38	7.36	0.02	1.30	0.49	0.81	3.00	6.3	-3.30
	25	13.80	8.21	5.59	10.59	9.60	0.99	1.80	0.94	0.86	2.00	8.5	-6.50
	50	14.58	7.90	6.68	6.16	6.70	-0.54	4.20	1.05	3.13	17.5	11.5	- 6.0
	75												

Table 3 continued

1	2	USA 3	USSR 4	5	USA 6	USSR 7	8	USA 9	10	11	USSR 12	13	14
17	0	-	7.99	-	7.06	6.83	0.23	-	0.59	-	-	8.4	-
	10	-	8.17	-	7.04	6.98	0.06	-	0.82	-	-	6.3	-
	25	-	8.10	-	8.19	8.76	-0.57	-	0.95	-	-	7.5	-
	50												
	75												
18	0	-	7.92	-	6.89	-	-	0.90	0.16	0.74	1.50	1.0	-0.40
	10	-	8.07	-	6.87	6.94	-0.07	0.80	0.43	0.37	1.50	3.1	-1.60
	25	-	8.10	-	8.40	8.83	-0.43	1.50	0.72	0.78	0.90	5.5	-4.60
	50												
	75												
19	0	-	8.05	-	8.37	7.46	0.91	0.50	0.33	0.17	1.50	7.3	-5.80
	10	-	8.39	-	8.36	8.46	-0.10	0.40	0.49	-0.09	1.50	7.3	-5.80
	25	-	8.13	-	9.23	8.46	-0.77	0.40	0.15	0.24	1.50	6.3	-4.80
	50												
	75												

44

Table 3 continued

1	2	USA 3	USSR 4	5	USA 6	USSR 7	8	USA 9	10	11	USSR 12	13	14
20	0	-	8.	-	8.10	6.95	1.15	0.30	0.33	-0.03	0.50	7.3	-6.8
	10	-	8.27	-	8.10	6.89	1.21	0.30	0.33	-0.03	1.0	7.3	-6.3
	25	-	8.16	-	9.96	7.92	2.04	0.60	0.49	0.11	1.0	7.8	-6.8
	50												
	75												
21	0	-	8.26	-	8.19	7.03	1.16	0.50	0.66	-0.11	0.50	6.3	-5.8
	10	-	8.34	-	8.24	6.98	1.26	0.50	0.49	-0.00	0.05	6.3	
	25	-	8.06	-	9.98	8.36	1.62	0.90	0.51	0.39	8.50	12.7	-4.2
	50	-	8.02	-	9.02	8.30	0.72	0.90	0.66	0.24	9.00	16.8	-7.8
	75												
22	0	-	8.25	-	8.85	7.39	1.46	0.40	0.33	0.07	0.40	8.4	-8.0
	10	-	8.34	-	8.82	8.08	0.74	0.50	0.33	0.17	0.50	8.8	-8.3
	25	-	8.24	-	9.51	8.16	1.35	0.70	1.08	-0.38	0.70	9.2	-8.5
	50	-	-	-	9.20	-	-						
	75												

45

Table 3 continued

1	2	USA 3	USSR 4	5	USA 6	USSR 7	8	USA 9	10	11	USSR 12	13	14
23	0	-	8.39	-	8.28	6.93	1.35	0.40	0.16	0.24	3.00	6.5	- 3.5
	10	-	8.44	-	8.32	7.08	1.24	0.30	0.16	0.14	2.50	6.3	- 3.8
	25	-	8.34	-	9.29	7.40	1.89	1.30	0.28	1.02	9.00	11.9	- 2.9
	50	-	8.03	-	7.47	6.89	0.56	2.80	0.63	2.17	38.00	27.2	10.8
	75	-	7.97	-	7.31	6.43	0.88	3.10	0.79	2.31	45.00	42.3	2.7
24	0	-	8.22	-	8.35	7.03	1.32	0.90	0.16	0.74	4.30	6.3	- 2.0
	10	-	8.31	-	8.32	7.08	1.24	1.20	0.20	1.00	4.20	6.3	- 2.1
	25	-	8.28	-	8.71	7.63	1.08	1.40	0.26	1.14	7.50	15.2	- 7.7
	50	-	8.14	-	8.54	7.26	1.28	2.50	0.95	1.55	37.0	37.7	- 0.7
	75	-	8.02	-	7.56	6.48	1.08	2.80	1.94	0.86	51.5	46.1	5.4

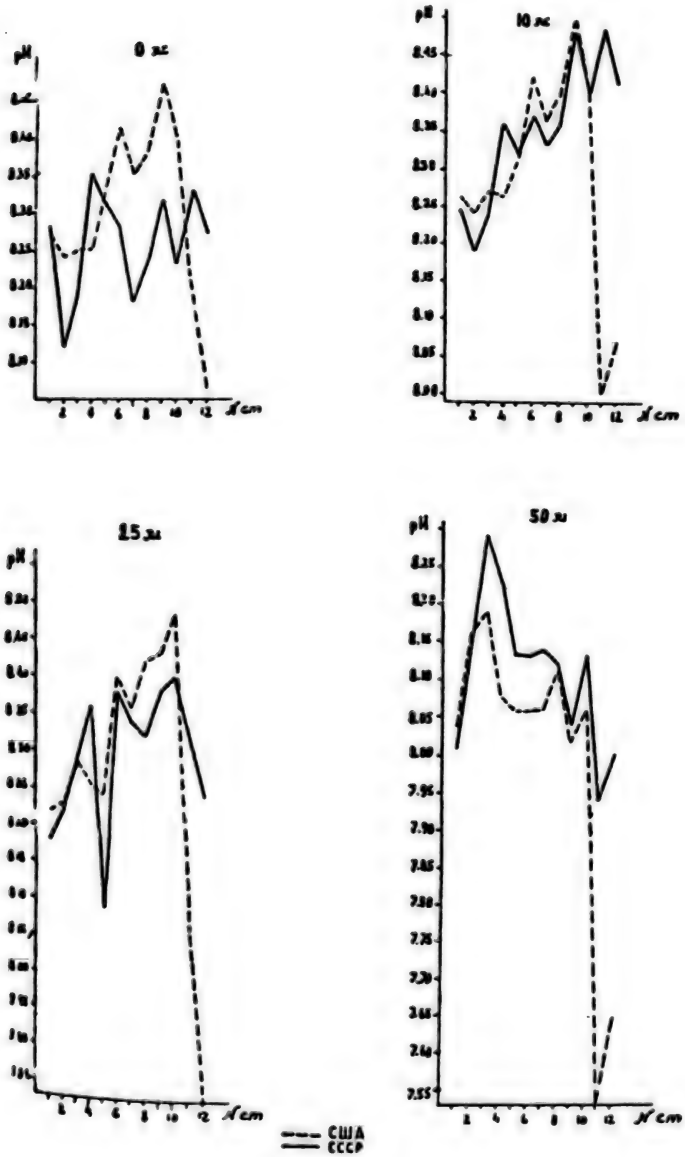

Figure 6. Soviet and American pH data.

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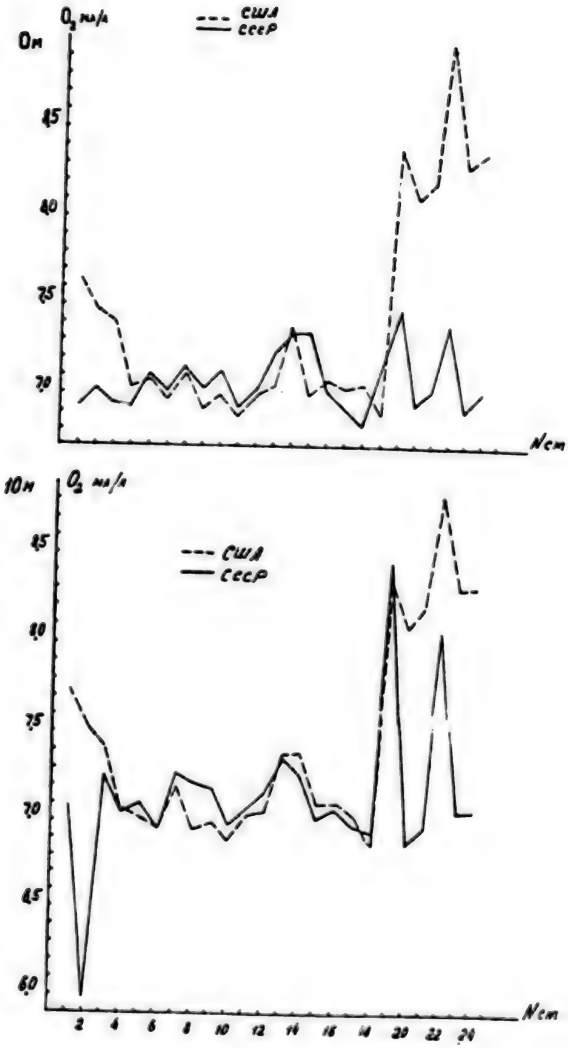

Figure 7. Comparison of Soviet and American oxygen data.

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pH, phosphates and silicon were taken for the comparison.

Since observations of American scientists covered the depth of 75 km, horizons coincident with the Soviet observations 0, 10, 25, 50, 75 were taken for the comparison. Table 3 and the plots presented below give the comparison of hydrochemical elements.

Concentrations of all the ingredients to be determined are given in one and the same units. Oxygen content in ml/l, pH active reaction in negative decimal logarithms, biogenous substances in ug-at/l. The plots verify values from station to station as well as the difference in value (Fig. 6).

pH active reaction values determined by American scientists were taken for 12 stations only since the rest of them were doubtful. The maximum difference was 0.41, minimum - 0.01. The sign of deviation value depth and from station to station is similar to that of ours.

While comparing data on oxygen concentrations similar variations and distribution character are revealed. Maximum absolute deviation value was 2.04 ml/l, minimum - 0.02 ml/l (Fig. 7).

Trace Metals

1) USSR

Water was sampled for its metal content through the use of a Niskin Bathometer at various depths. A Kapron net with a 1 mm x 1 mm mesh was used to sample the surface microlayer.

One-hundred ml of sea water was placed in a glass

beaker and acidified with 6-mole HNO_3 to a pH of 3.
One ml of a solution containing 100 mg of chemically pure $Pb(NO_3)2$ was added to the beaker, and hydrogen sulfide bubbled through deionized water was passed through the solution for one minute. The hydrogen sulfide was obtained by the reaction of hydrochloric acid and iron sulfide. The resultant black precipitate of lead sulfide with metal sulfides coprecipitated on it was filtered onto "blue ribbon" filter paper, washed with deionized water, dried at room temperature and packed in clean polyethylene packets.

The coprecipitation factor of all the metals under investigation was practically 100%, which was confirmed by the appropriate radioactive indicators.

The methodology employed for determining the metals in water is described in Stepanov and Artemyev (1977).

2) USA

Three different sampling systems for trace metal analysis were tested on this cruise. Although ideal for trace metal sample collection - no metallic parts are immersed into the ocean - a system utilizing a High Capacity Masterflex tube pump (Cat. No. 7109) connected to 75 meters of 3/4" I. D. polyethylene tubing proved unsatisfactory for open ocean operations. An Interocean System Model 513D CSTD unit, fitted with a submersible pump was installed on this ship for this cruise. Because the sample contacted metallic parts with this system, it was not used for trace metal sampling. However, some samples, as a matter of interest, were collected, analyzed for copper and

lead and the data compared to copper lead data collected from the same depths with 1.7 liter PVC Niskin bottles. The results of this work confirmed the undesirability of the Interocean System for trace metal sampling; since all samples analyzed were higher in copper and lead concentrations. Inspection of the intake of the submersible pump and the interior of the sample outlet system indicated corrosion at both places. All samples, consequently were collected in 1.7 liter PVC Niskin bottles which were scrubbed thoroughly with hot soapy water, washed and subsequently soaked overnight in dilute 5% nitric acid solution, washed with and then soaked for 24 hours in seawater. Seawater samples were filtered on deck by pumping directly from the Niskin bottles with the Masterflex tube pump through an 0.45 Nucleopore filter contained in an in-line Millipore filter holder. Between 200 and 300 ml of seawater was pumped through the entire system and discarded before any sample was collected. Subsequent to filtering, 1.0 ml of a dilute mercuric nitrate solution (Hg metal dissolved in Ultrex nitric acid and diluted with triple distilled water) was immediately added to the samples. The mercury concentration in the samples was approximately 4×10^{-5}M Hg and the pH was approximately 2.5.

Surface Microlayer Samples

Surface microlayer samples were collected with a 1.00mm pore size polyethylene screen mounted in a plexiglass frame. Samples were collected from a small boat about 1-2 km away from and windward of the Volna. The screen was dipped under the water and raised through the sea surface from below. The surface microlayer 100-200u collected on the screen was drained into a 250 ml

pre-cleaned polyethylene bottle. These samples were not filtered but 1.0 ml of mercuric nitrate/HNO_3 solution was added. The final pH was approximately 2.5. To complement these data, closely spaced (10-15 cm distance) samples were collected from the top 1 m of the ocean with a free-floating sampler. Samples collected with this sample were filtered through 0.45 Nucleopore filters and acidified (pH 2.5), and made approximately 4×10^{-5}M in mercury. The purpose of this latter effort was to determine trace metal gradients in surface waters which would indicate either supply to or removal from the surface microlayer. Surface microlayer samples were collected on an opportunity basis, dictated by weather conditions. Two stations only were occupied for surface microlayer work.

All samples were analyzed by differential pulsed anodic stripping voltammetry with glass carbon electrodes. A PAR Model 174 polarographic analyzer was used for analysis. The instrumentation was set up on board ship and approximately three-quarters of all samples collected were analyzed during the cruise. The remaining samples were analyzed at IMS, University of Alaska about two months after termination of the cruise. These latter samples were stored frozen for most of this period.

The analysis procedure briefly was:

1. 50 ml of seawater is placed in the electrolysis cell and nitrogen gas bubbled through for 10-15 minutes.
2. Cu and Pb are deposited simultaneously with Hg on the glassy carbon electrode by plating at -0.75 V (calomel reference) for 5-15 minutes, depending upon element concentration in the sample. Cu, Pb and Hg are stripped from the electrode

by scanning the voltage range in an anodic direction. The first plate-strip cycle serves to determine an optimum analysis time and to condition the electrode.

3. Cu and Pb current peak heights are recorded on a successive plate-strip cycle. Hg is stripped from the electrode at each step.

4. The concentration of copper and lead in the sample is determined by the method of standard additions. At least two additions of standards were added to every sample. A least squares line was fitted to the data points. The precision of this technique is approximately 10%.

Water Column Trace Elements

1) USSR

In view of the fact that lengthy storage of the water samples, even under acidification, can result in possible loss of chemical elements to the walls of the container, we decided to carry out preliminary separation of all the elements on board ship. Lead sulfide was used for this.

In this process 1 milliliter of a 10% solution of chemically pure $Pb(NO_3)_2$ was added to 100 milliliters of acidified sea water, and PbS was precipitated by passing H_2S through the liquid. In the process, a large number of elements were precipitated. In parallel with this, blank samples were prepared with double-distilled water.

For analysis the method of neutron activation was used. We conducted determinations of only those elements which could be identified after a

relatively short period (20 hours) of irradiation in the reactor with the particular instrument we had available. The elements Zn, Co, Fe, Sc, Au, Br, Hg and Sb were determined.

The analysis of the samples was carried out at the VVP-Sm reactor with a neutron current of 10^{13} neutrons per sq cm per sec. The measurement of induced activity was made with a Ge(Li) detector with 90 cm^2 volume, and a multichamber analyzer with minicomputer. The identification of the isotopes was made from the following gamma lines: Br^{82}, 554 keV; Au^{198}, 411 keV; Cr^{51}, 320 keV; Fe^{59}, 1098 keV, Hg^{203}, 279 keV; Co^{60}, 1172 keV; Sb^{124}, 600 keV; Sc^{46}, 889 keV; Ag^{110m}, 656 keV, and Zn^{65}, 1115 keV. In the calculation of the content of Sc^{46}, the contribution from Ag^{110m} to photopeak 889 keV was taken into account, and also the contribution of Sc^{46} to the photopeak of Zn^{65} at 1115 keV.

The detection limits for the various elements are as follows: Br, 3×10^{-8} g; Au, 2×10^{-8} g; Cr, 5×10^{-8} g; Fe, 10^{-6} g; Hg, 10^{-7} g; Co, 8×10^{-8} g: Sb, 5×10^{-8} g; Sc, 10^{-7} g; Ag, 10^{-8} g; and Zn, 3×10^{-6} g.

The determination of the content of the elements in water was carried out after irradiation of the PbS coprecipitation. The correction for the blank samples prepared with distilled water was insignificant for all elements.

Trace Elements in Plankton

Samples for the determination of trace elements in plankton were collected from the **near surface layer and the 0 to 50 meter layer.**

The plankton samples were collected with a Jeddy net (BSD) of diameter 37 cm made of No. 61 miller's screen. The samples were taken from the layers 50 to 0 and 5 to 0 meters. The size of the openings in the miller's screen was 0.15 to 0.16 mm, which made it possible to capture the main species of zoo- and phytoplankters. The samples were filtered and dried between sheets of filter paper, and then weighed to determine the biomass. Thereafter the plankton samples were dried to constant weight at a temperature of 105° in a drying cabinet over a 24-hour period, weighed and inserted in polyethylene sleeves, in which state they were sent for analysis.

The average value of the plankton biomass for stations 1 to 24 was 0.4 g/m^3; and for stations 25 to 48 it was 1.2 g/m^3.

The plankton samples were sent to be analyzed in the dry state. Therefore the results of the determination of the weights of the plankton samples after drying and comparison of these with the wet weights are of interest. These results are shown in Table 17. The coefficient which reflects the change in weight after drying

$$K_{W_i} = (\text{wet weight})/(\text{dry weight}),$$

varied from 7 to 30 among the different samples. The apparent cause of such variation is the variation in species composition of the plankton. For analyzing the plankton samples the method of neutron activation was used. We conducted determinations of only those elements which could be identified after a relatively short period (20 hours) of irradiation in the reactor with the

particular instrument we have available. Among the elements determined, in addition to zinc, cobalt, iron, scandium, gold, and bromine, there were also the toxic elements mercury and antimony, the determinations of the concentrations of which are particularly current and urgent assignments in connection with the problems of pollution of environmental media.

As was mentioned above, the analysis was carried out on plankton samples which had been dried to constant weight. Thus initially the content of the elements was calculated on the basis of the dry weight. Using the coefficients of conversion from dry weight to wet weight and to the biomass of the plankton (Table 18), the concentrations of Hg, Sb, Zn, Cr, Sc, Fe, and Co were calculated per unit biomass of the plankton, for each station. These data are given in Table 18 .

Accumulation coefficients of Hg, Sb, Zn, and Cr in the plankton were also calculated for stations 1 to 24, according to the formula:

$$K_{acc} = (C_{i\ (plankton)})/(C_{i\ water}),$$

where $C_{i\ plankton}$ is the concentration of the i-th element in the plankton based on raw weight, and $C_{i\ water}$ is the concentration of the i-th element in the water. These data are shown in Table 20 .

Analogously, the samples of surface plankton were analyzed for their content of Fe, Cr, Zn, and Co. In some of these samples, mercury was also analyzed. The reason for not determining the other elements was the small size of the samples.

In some plankton samples the determination of the metals was carried out

by the method of atomic absorption. Weighed portions of dry plankton were ashed in a muffle furnace at a temperature of 450°C, after which the ash was dissolved in a mixture of hydrofluoric and nitric acids, and resulting solution was subjected to the determination of the metals.

A comparison of the results of Tables 18 and 21 shows that the concentrations of zinc and iron measured by neutron activation and atomic absorption are of the same order of magnitude but still differ by small number of factors.

Low Molecular Weight Hydrocarbon in Water (USA)

The hydrocarbon measurements were made by gas chromatography on board the M/V Volna. In this technique, the dissolved hydrocarbons were first stripped from solution by purging with helium, and then concentrated in cold traps containing appropriate adsorbents; they were subsequently released by an increase in temperature and swept into the gas chromatograph by a second stream of helium carrier gas. With this method, sample size was not restricted, and very dilute solutions may be analyzed.

Two cold traps at -77°C were used in series. In the first, activated alumina was used to trap all hydrocarbons except methane and carbon monoxide; in the second, a mixture of activated charcoal and molecular sieve was used to trap methane and carbon monoxide. When the stripping was complete, the traps were isolated by closure of appropriate valves, and their temperature was raised to approximately 90°C. Helium carrier gas was then used to strip each adsorbent, in turn, of the adsorbed gases, and to carry these gases into the chromatograph

for further separation and analysis. A four-foot column containing activated alumina with 10% Nujol was used to separate low-molecular-weight hydrocarbons other than methane. Methane and carbon monoxide were separated on a molecular sieve column.

For the light hydrocarbons, the absolute sensitivity of the method is approximately 2×10^{-12} mol. On the basis of 1-liter water samples, this sensitivity corresponds to 5×10^{-8} ml of dissolved gas at standard temperature and pressure (STP) per liter of seawater. At this lower limit, the precision of the method, on the basis of replicate measurements under laboratory conditions, is $\pm$ 10%. For quantities of gas greater by a factor of 10 or more, the precision improves to $\pm$ 1.0% Additional error incurred during field operations may increase this spread in uncertainity. The chromatograph was calibrated with a commercially available gas mixture containing known amounts of the hydrocarbons to be tested.

Water samples were obtained from 1.7-liter Niskin bottles. The samples were drawn in the same manner as oxygen samples into 1.2 liter Pyrex bottles with tapered ground glass joints. The samples were immediately put in the dark and analyzed as soon as possible, usually immediately after the station was completed. The main bulk of water samples were taken using the on-board Interocean pumping system. The pumping system was not used for the hydrocarbon samples. The pump and cable are identical to the system fabricated and used by Naval Research Laboratory personnel. The reason for not using the pumping system was due to the contamination of water samples with butane and higher organic compounds. The source of contamination apparently was from a short section of rubber garden hose used as the termination point for the pumping system.

High Molecular Weight Hydrocarbons and Benzo(a)pyrene (USSR)

The water samples for determining hydrocarbons and benzo(a)pyrene were taken from the surface microlayer and from depths of from 0 to 50 meters. The surface microlayer was sampled from the bow of the ship with a pre-cleaned metallic screen of diameter 30 cm with cell size 1 x 1 millimeter. This enabled the sampling of a surface layer of water of thickness 200 to 400 microns. The surface microlayer sample taken for analysis amounted to 500 milliliters of water, while others from the various depths amounted to 2 liters each.

The extraction for the determination of hydrocarbons was carried out by shaking the water sample with glass distilled (2x) carbon tetrachloride added in the proportion 25 milliliter CCl_4 per liter of water, in a separatory funnel for 10 minutes. Then the extract was decanted, a new portion of carbon tetrachloride was added, and the mixing process was repeated. Two extract portions were decanted and combined, dried, and preserved for further processing ashore. The extraction procedure for determining BP in the water is analogous to that for hydrocarbons, but benzene is used in place of CCl_4.

The analysis for total hydrocarbon content was carried out at a shore laboratory on an infrared spectrometer, and that for BP was performed by a fluorescent method making use of the Shpol'skiy effect.

Hydrocarbons and Benzo(a)pyrene (in Plankton) (USSR)

Determination of BP were also carried out on several plankton samples. After the plankton was dried to constant weight in a drying cabinet at a temperature not exceeding 100° Centigrade, 200 mg of the dried residue were taken for extraction with benzene and for subsequent determination of their BP content.

Biological

1) Chlorophyll a (USA)

Water samples for determining chlorophyll a were collected from the surface, 10m, 25m, 50m and 75m or just above the bottom (5m) with a submersible pump.

One liter samples for chlorophyll analysis were filtered within one hour of collection through Whatman GF/C 4.5 cm glass filter pads and frozen after treatment with a 1% magnesium carbonate suspension. Upon completion of the expedition the chlorophyll samples were shipped frozen with Dry Ice and were analyzed within two weeks of the expedition's end. The fluorometric method (in Strickland and Parsons 1972) which can detect .01 mg chlorophyll a/m^3, was used for analysis of chlorophyll a.

2) Phytoplankton and Zooplankton (USSR)

Samples of plankton were taken with a Jeddy net (diameter of the included opening was 37 cm, with No. 61 netting) in the 0 to 50 m layer. The samples were fixed with 4% buffered formalin. In the workup of the samples, the age distribution and population of the dominant species of zooplanktons and the relative abundance of the dominant species of phytoplanktons were determined. Duplicate counts were made of the organisms under a binocular microscope, in a Bogorov chamber. Over the period of the expedition, 48 stations were covered with 257 plankton samples being taken.

RESULTS

Meteorology

1) Synoptic Processes and Weather Conditions

The comparison of mean surface pressure charts for August 1977 (Fig. 8) with mean data for many years showed that over the northern-western part of the Pacific ocean the pressure was somewhat higher than normal. According to the data for many years the core of the Northern-Pacific anticyclone is located at 40°N, 150°W, but in August 1977 there were two cores of high pressure: one - at 40°N 180° (P=1020 mb) and the other near the coast of North America. (It is impossible to present accurate co-ordinates, since data for the mean chart were taken from daily surface charts of RMC Tokyo for 00GMT). In August 1977 the pressure over the Bering Sea was normal.

Cyclonic activity was weak in the first half of August. The region of cyclogenesis was near Baikal and Japan Islands, and northern trajectory, i.e. from Japan Islands to the Sea of Okhotsk to the North-East, to the northern part of the Bering Sea. The existence of a high-level anticyclone, with an eastern orientation, the Pacific Ocean, in addition to the western position of the high-level depression can determine the appearance of cyclones over the Bering Sea (Fig. 9). These cyclones as a rule were poorly developed. Their structures were low baritic formations and on the AT500 chart they were not detectible and their velocity changed with limits of 15 - 20 km/h.

The weather in the Bering Sea was determined by two somewhat factors:

Cyclones moving to the North of the test-site and Northern-Pacific anticyclone reach.

Continuous change of weather resulted from cyclones reachin the Bering Sea. For example on the 5th of August the northern part of the Bering Sea was reached by a cyclone with core pressure 922 mb with a frontal system, associated with it, crossed the region of work and caused enhancement of wind to 9 - 10 m/sec and rain. During the following days the weather was still because of the high pressure reach and was followed by cyclones.

It is evident from the data in Table 4 that during the expedition the weather was dreary with frequent rains. Fifty-nine percent of the days were foggy and wind velocities of 5-10 m/sec. predominated. The sea state was slight (2-3 m) and no storm winds were encountered.

Actinometric Observations

Diurnal variation of incoming and reflected solar radiation from the ocean surface may be represented by two typical days: by the day of 12 August 1977 with continuous cloudiness and by the day of 8 August 1977 with clouds of high levels (Fig. 4). Regular diurnal variation of incoming integral radiationwas observed in the day with slight cloudiness. Hourly sums of incoming heat were symmetric relative to noon (1200 hours) and its variation was subjected to the sun height variation during the day. Maximum radiation value 64 cal/cm^{2}h was at noon. On the day with continuous cloudiness the diurnal variation of incoming solar radiation was different from that of the day described above, it was not symmetric relative to noon and radiation maximum value of 28 cal/cm^{2}h which was observed in the period of 0900-1000 when the cloudiness was the least.

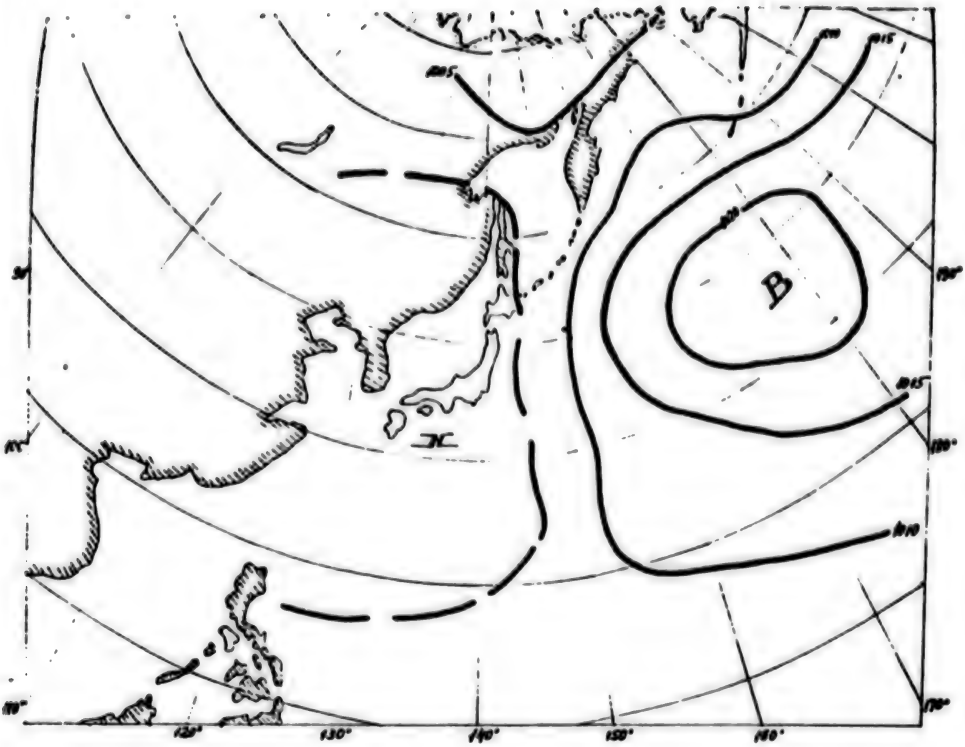

Figure 8. Chart of average surface pressure, August 1977.

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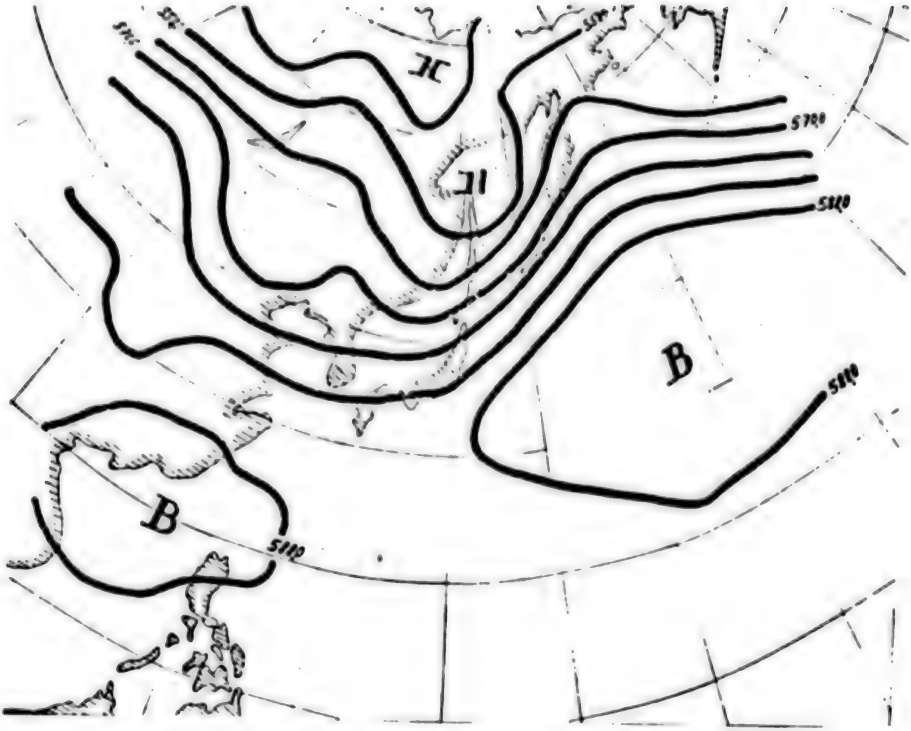

Figure [illegible]. Chart of average baroclinic topography, August 1977.

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[illegible] 4. Meteological Data of Bering Sea

[illegible] State			Rain	Fog	Wind Speed, m/sec			
[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]
18	1	3	8	13	7	12	3	-
72	4	14	[illegible]	59	31	55	14	-

Sea roughness, m

1-2	2-3	3-4	4
18	3	1	-
72	14	4	-

in numerator - number of days;

in dominator - repetition in per cent.

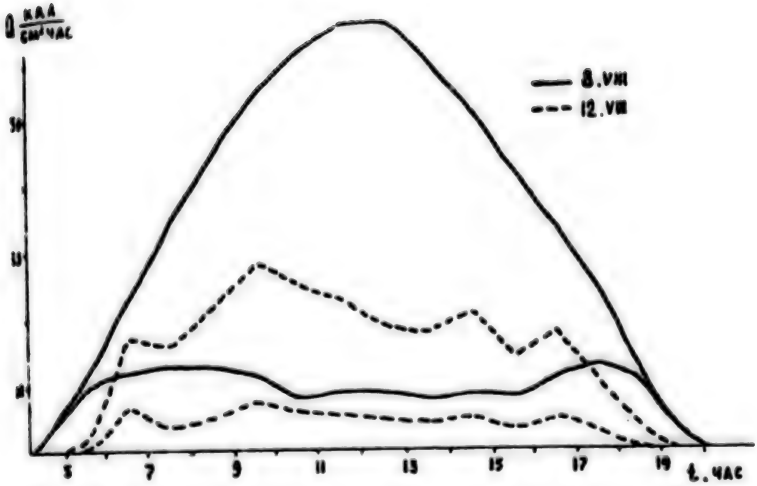

Figure 10. Daily curve of total and reflected radiation August 8, 12, 1977.

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Total diurnal sum of incoming radiation considerably changed on the days in question (8 August -Q=582 cal/cm^2 - 24 hours; 12 August -Q=226 cal/cm^2 - 24 hours) due to cloudiness variation. The difference between the greatest and the smallest sum of incoming radiation during the observational period was 70%. The atmospheric transparency over the test-site was high and the atmospheric transparency coefficient varied from 0.760 to 0.790.

Thus at the test-site cloudiness was the main factor reducing the income of solar radiation and correspondingly its reflection. Scattered radiation predominated over direct and made up the main per cent of incoming radiation in the diurnal variation.

During the observational period cloudy weather dominated and was typical of the region. The per cent distribution of total and low cloudiness during the daylight hours is shown in Table 5. During the period of observation low level clouds dominated (Fig. 11). Diurnal sums of incoming and reflected solar radiation for the observation period are shown in Table 6. Their mean value for the period was equal to 329 cal/cm^2 24 hours and 26 cal/cm^2 24 hours respectively. Isopleth plot of hourly sums were drawn on the basis of hourly sums of integral radiation (Fig. 12). There was no monotonous pattern of radiation variation in the plot.

Table 5

The percent distribution of total and low cloudiness during the daylight hours.

Amount of Clouds	Cloudiness % Total	:	Low
0-3	4		10
4-7	12		7
8-10	84		74

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	35	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	45	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

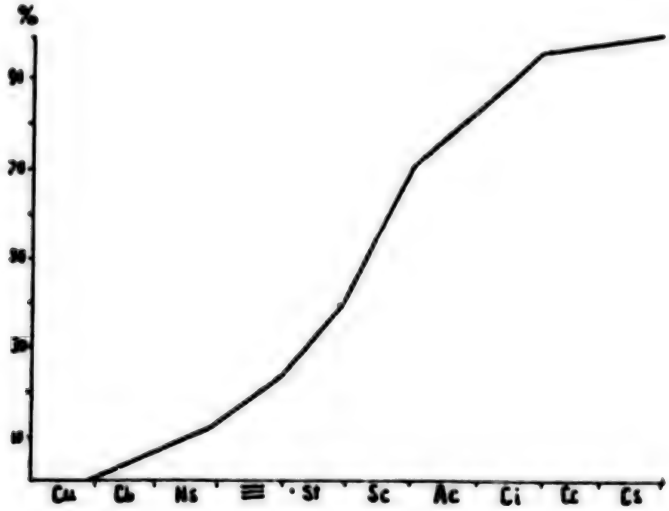

Figure 11. Frequency of occurrence of various cloud types.

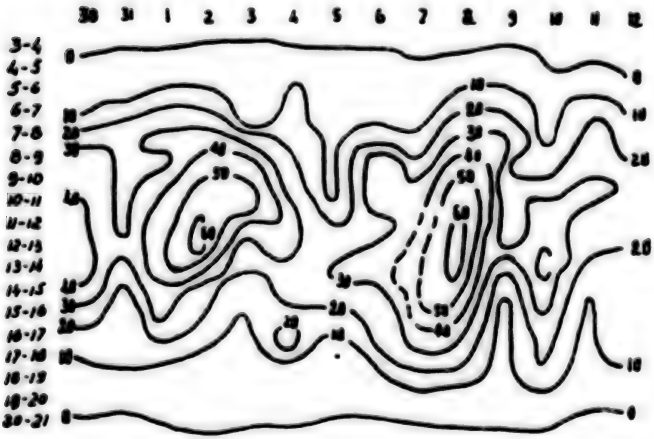

Figure 12. Daily variation in the total radiation 30 July - 12 August 1977.

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Among dreary days one can see days with slight to changeable cloudiness, which changed to a constant variation of hourly sums and three cells of high values appeared. The increase of hourly sum values on 2 August and 8 August resulted from the appearance of the Northern-Pacific anticyclone reach in the region. During these days a pronounced diurnal variation of hourly sums of incoming and internal radiation with maximum at noon (1200-1300 hours) was observed. On the rest of the days the maximum was shifted relative to noon and was observed either in the first or in the second half of day.

The relationship of the Northern-Pacific anticyclone and cyclones passing over the Bering Sea and the frontal system connected with them determined the weather conditions as well as the diurnal variation of incoming solar radiation.

Hourly sums from day to day during equal hour intervals were different from 30 July to 2 August during the first four hours and in the evening their difference was small.

The greatest maximum hourly sum of 64 cal/cm^{2}min per day was observed on 8 August when the amount of high-level clouds equalled two, three, and the least one - 2 cal/cm^{2}min - on 12 August when the amount of low-level clouds equalled to ten.

The diurnal sum of reflected radiation with minimum value 12 cal/cm^2 24 hours was observed in August 5, the maximum - 45 cal/cm^2 24 hours - August 8. This variation amounted to 71%. Constant variation from day to day of the

reflected radiation was not observed and its value was subjected to the character and amount of clouds.

To characterize the heat albedo variability of the sea surface we drew plots of the diurnal variation of its hourly values (Fig.13)

The figure shows the daily variations of albedo for the most characteristic conditions: 8 August - slight cloudiness, 10 August- changible cloudiness, 6 August - continuous cloudiness.

On the day with the least cloudiness daily albedo variation was pronounced. A minimum value of 4% of albedo was observed about noon (1100-1500 hours), and in the morning and evening it increased to 28%. During days with continuous cloudiness diurnal albedo variation was of a smooth character (from 0600 to 1400 hours albedo was equal to 6%) and it increased slightly (by 2-4%) in the morning and evening. Such a variation of albedo hourly sums dominated during the cruise. On days with changible cloudiness there was no pronounced albedo variation.

Hourly mean values of albedo variations during the observation period were increased by evening, at noon time during 8 hours it was almost constant and equalled 6-7%.

Albedo of diurnal sums of the reflected radiation in characteristic days (6, 8, 12 August) was 6, 8, and 8% respectively. Mean albedo value of diurnal sums for the entire observation period was 8%.

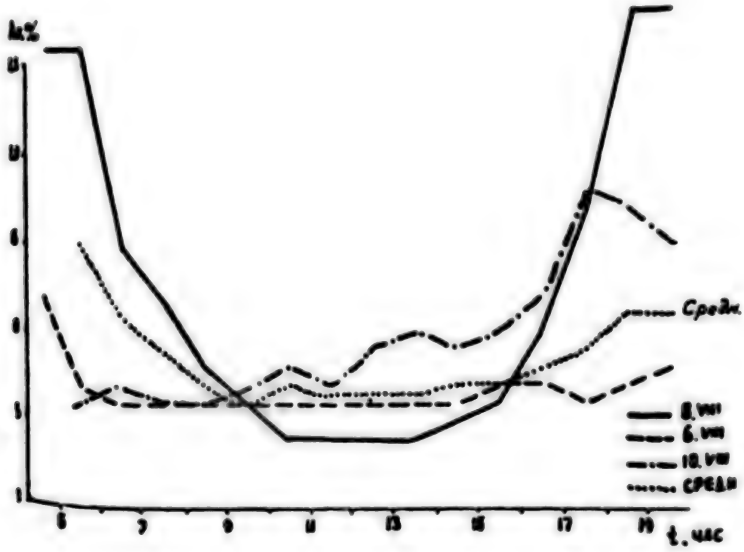

Figure 13. Daily variation in albedo.

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Atmospheric Chemistry

1) Radioactive Materials

The concentrations of Pb^{212} and Pb^{214} were determined with the aim of surveying the air mass to study the pollution of the atmosphere, the reasoning behind this being that these nuclides have a purely continental origin.

In Table 7 the daily average concentrations of the radio-nuclides in the study area are shown.

Since samples for radionuclides were taken four times a day, Table 7 shows the minimum and maximum concentrations of Pb^{214} in the four sample (numerator) and the mean value (denominator). High concentrations of Pb^{214} were generally observed in only one sample of the four. The samples of 8/8/77, in which high values were observed in three of the four samples, are an exception.

As indicated, the average concentration of Pb^{214} varied over the range 2.35×10^{-15} to 11.0×10^{-15} curies per liter.

2) Sulfur Dioxide

The results of the determination of sulfur dioxide concentrations in the layer of atmosphere near the surface of the sea are shown in Table 8.

The concentration of sulfur dioxide in the central region of the Bering Sea varied from 0.08 to 0.20 g/m^3 (over seven samples). An exception was sample S-8, in which the SO_2 concentration was several times higher than previously and this was attributed to shipboard contamination.

3) Trace Metals

Table 9 shows the concentration of selected trace metals in the atmosphere near the sea surface.

Table 7. The daily concentration of Pb^{214} and Pb^{212} in the study area.

Date of Sample	Concentration of isotope in air (curies/liter) · 10^{-17}	
	Pb^{214}	Pb^{212}
7/30/77	490-1309 / 840	0
7/31/77	230-260 / 235	0
8/1/77	235-512 / 430	0
8/2/77	316-437 / 380	0
8/3/77	303-354 / 315	0
8/4/77	623-1420 / 800	18.3
8/5/77	306-527 / 380	0
8/6/77	230-750 / 420	0
8/7/77	315-604 / 490	0
8/8/77	520-1200 / 750	8.3; 15; 17.4; 0
8/9/77	663-1400 / 759	15
8/10/77	960-1490 / 1100	19.4
8/11/77	490-1100 / 620	10.9
8/12/77	460-647 / 520	0

Table 8

The atmospheric concentration of sulfur dioxide near the sea surface.

Sample No.	Date of start of sampling (Station#)	Date of end of sampling (Station#)	C SO_2, (Bubbler) ug/m^3	C SO_2, (Solid Sorbent) /sic/ ug/m^3	Concentration of SO_2, ug/m^3
S-1	30 July (1)	1 August (7)	0.07	0.10	0.09 ±
S-2	1 August (7)	2 August (12)	0.17	0.15	0.16
S-3	2 August (12)	4 August (19)	0.11	0.08	0.10 ±
S-4	4 August (19)	6 August (24)	0.21	0.23	0.22
S-5	6 August (24)	8 August (31)	0.08	0.07	0.08 ±
S-6	8 August (31)	9 August (36)	0.18	0.20	0.19
S-7	9 August (36)	11 August (43)	0.13	0.12	0.13
S-8	11 August (43)	12 August (48)	0.54	0.56	0.55

Table 9

The atmospheric concentration of trace metals near the surface of the sea.

Sample No.		Inorganic Component, $\mu g/m^3$	Cu	Zn	Pb	Cd	Ni	Fe	Mn
F-1 etc.	1	9	10.7	7	4.9	0.05	1.1	20	306
	2	8	7	7	0.5	-	1.5	85	290
	3	11	3	13	1	-	0.3	63	380
	4	15	5	2	6	0.1	0.8	50	540
	5	12	6	3	3	-	1	15	415
	6	10	2	5	5	0.2	0.7	30	350
	7	9	7	9	0.8	-	0.7	90	310

4) Hydrocarbons

Sample locations, times, average wind velocity and temperature are shown in Table 10.

The data on the hydrocarbon content in the samples and in the atmosphere are presented in Table 11.

The observed differences in hydrocarbon concentrations were small and were not considered to be significant.

Fig.14 shows a chromatogram from filter F-2, which is also characteristic of the two other aerosol samples. The peaks on this chromatogram are normal alkanes, while the "hump" from which they extend was composed of unresolved peaks of naphthenic and aromatic hydrocarbons. The maximum of the "hump" was located in the area of the C_{26} to C_{28} hydrocarbons.

5) Benzo(a)pyrene

In the sample F-4 the concentration of benzopyrene in the atmosphere was approximately 0.1 ng/m^3, while in sample F-5 the concentration was 0.2 ng/m^3. The average concentration of benzo(a)pyrene near the sea surface was 0.15 ng/m^3. The number of samples was too small for generalizations on the atmospheric distribution of benzopyrene to be made.

Hydrologic

Figures 15 to 18 show the vertical and horizontal distribution of temperature and salinity.

The data indicates that this region of the Bering Sea can be divided into two parts. The dividing line along the front was evident in the salinity field (Fig. 16.) Maximum salinity variations of $1^{o}/oo$ per 30 miles characterized this region. Waters with stable stratification were found to the north of this front. A uniform surface layer with lower salinity ($30.00-31.00^{o}/oo$) and temperature ranging between $9-10^{o}$ was evident. The depth of the water was 10m.

Table 10

Sample locations, times, average wind velocity and temperature.

Sample No.	Date of Sampling	Station No. of Sampling Location Start	Finish	Volume of Air Passed thru, cu, meters	Ave.Air Temp. °C	Ave.wind Speed,
1	July 30 August 1	1	7	2700	9.5	4
2	August 1-2	7	12	2500	9	4.5
3	August 2-4	12	19	2000	9.5	8
4	August 4-6	19	24	2300	10	10
5	August 6-8	24	31	2200	9.8	9
6	August 9-11	36	43	2500	10	5
7	August 11-12	43	48	2400	9.8	5

Table 11

Sample No.	Total Hydrocarbons in Sample mg	Concentration of Hydrocarbons ug/m^3
F-1	2.4	0.79
F-2	2.1	0.72
F-3	1.9	0.90

The thermocline was present between 10-25 m. The gradient of the thermocline was $1^{\circ}/m$ in temperature and 0.10%./m in salinity. The salinity in the discontinuity layer varied from 30.80% at the upper boundary to 32% at the lower boundary and temperature varied from $1.0-1.5^{\circ}$.

The waters below the thermocline were uniform and were characterized by temperature and salinity of $-1.5-1.7^{\circ}$ and 31.80-32.1% respectively.

Near bottom cold waters were located at depths of 20m in the northern regions and at approximately 45m in the frontal region.

Near bottom cold water is formed in the shallow water during autumn-winter cooling, its salinity is enhanced while icing. In the early spring-summer season warming of surface waters stimulates the thermocline formation which preserves the negative temperature anomaly for a long period of time.

The thermocline reached the surface to the north-east of the test-site (Fig. 17) and in the surface region (0-10m) water temperature was $10-11^{\circ}$ while salinity decreased to $30^{\circ}/oo$. Near bottom cold water was driven away from Alaska coasts and is evidently related with streams of river run off which flow to the North.

A warm water jet is found within the frontal zone with temperature $10-11^{\circ}$ (Fig. 16+18). The 10° isotherm was present at depths of 10-16 m. Apparently a Pacific warm jet approaches the continental shoal and pushing against St. Matthew Island turns to the North and North-West.

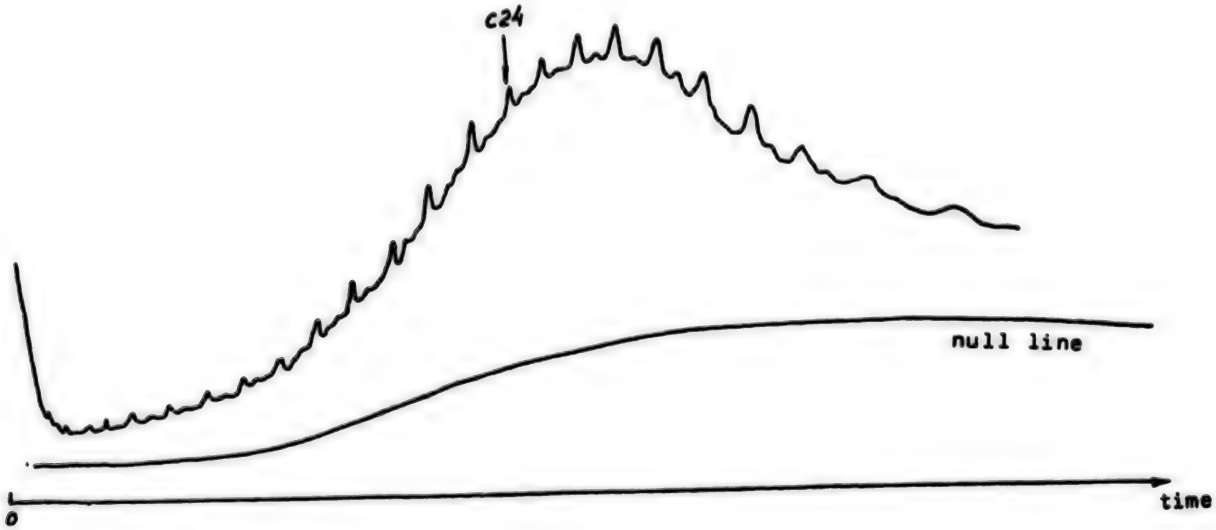

Figure 14. Chromatogram of Filter F-2.

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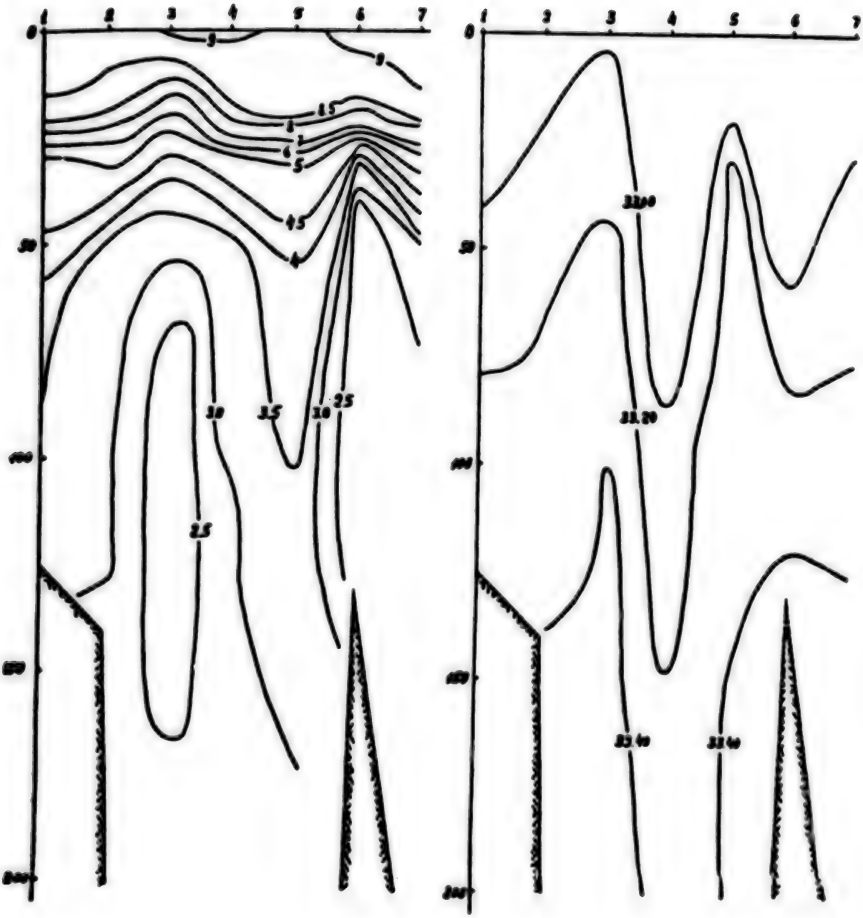

Figure 15. Vertical distribution of temperature and salinity along Transect No. 1.

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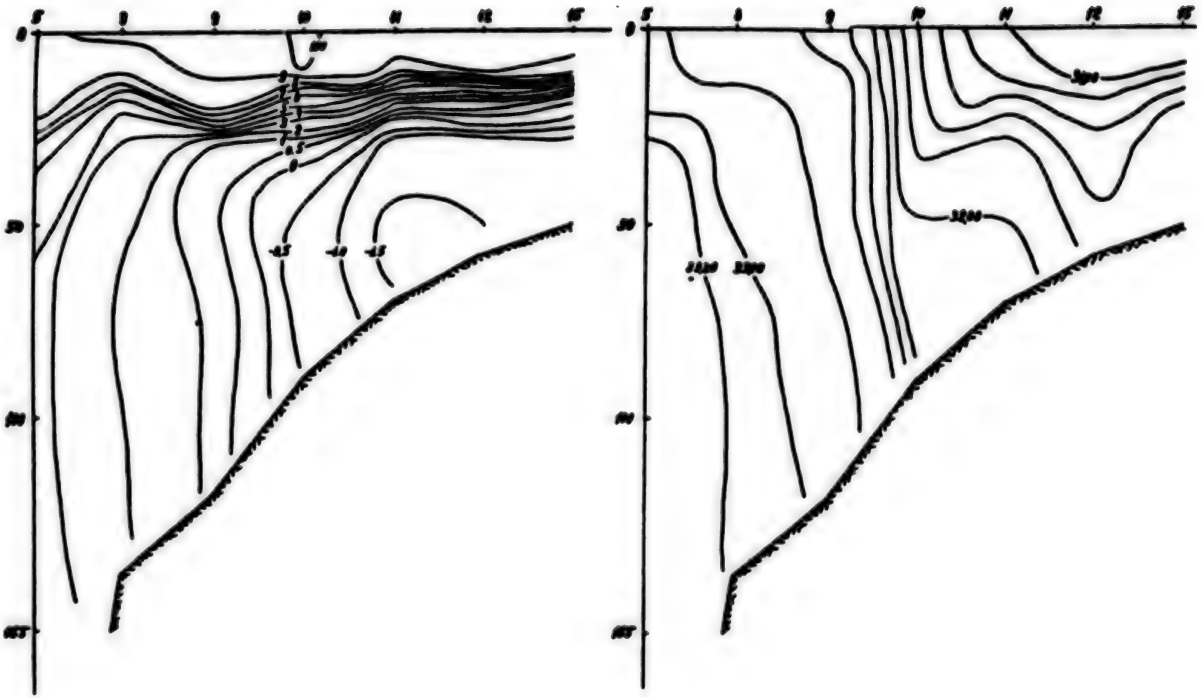

Figure 16. Vertical distribution of temperature and salinity along Transect 4 . 12.

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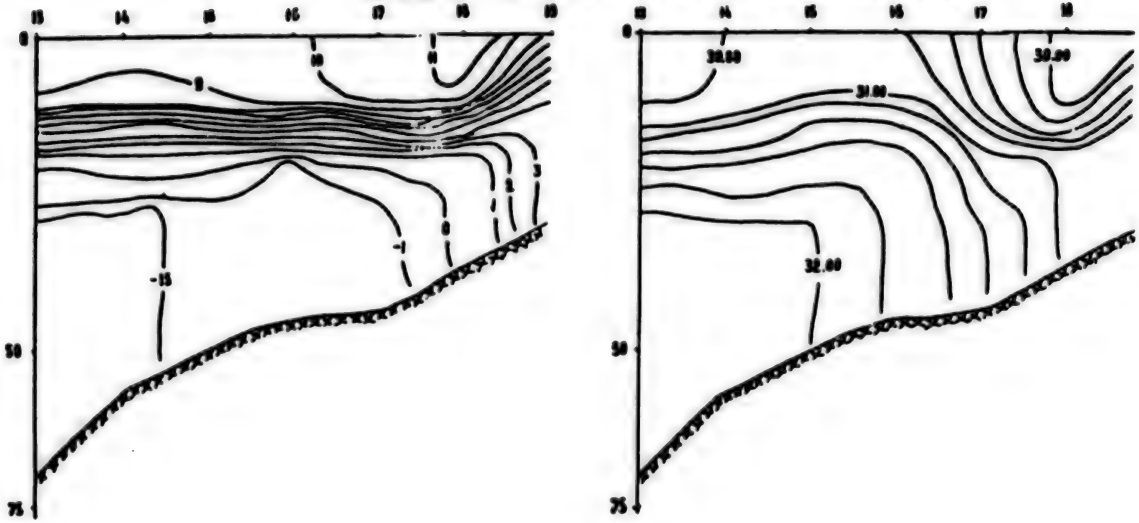

Figure 17. Vertical distribution of temperature and salinity along transect No. 4.

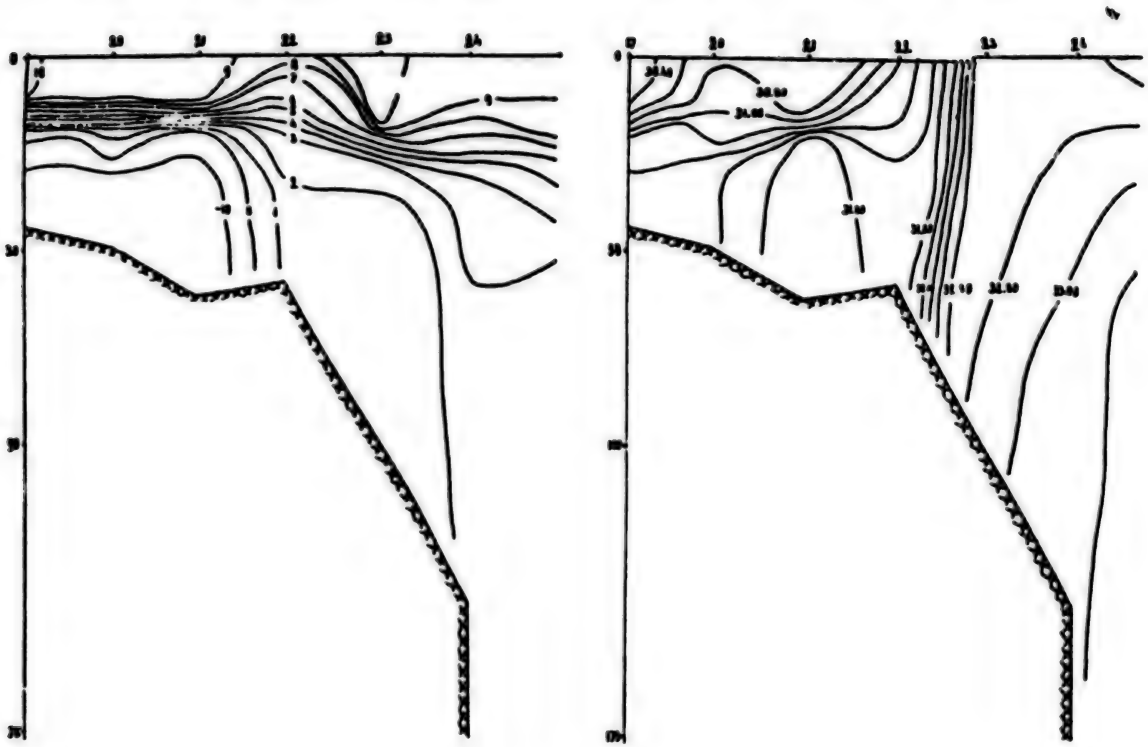

Figure 18. Vertical distribution of temperature and salinity along transect.

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85

To the South of the boundary mentioned above almost vertical isotherm and isohaline were observed from 30-50 m depth to the bottom and this testifies to the vertical movement of water (Figs. 16 and 18).

Isotherm and isoline convexities and concavities, profile No. 1 (Fig. 15), indicate the vertical movement of the water.

The discontinuous layer while passing (from North to South) over the front became less pronounced and its lower boundary sank to 50 m. The gradients were lower and amounted to 0.12°/m in the temperature field. Gradients in the salinity field were negligible.

Salinity increased from 33.00 to 33.[illegible]°/oo and temperature decreased from 8.5 to 9°C at the surface from the North to South. This is attributed to the inflow of Pacific saline water and mixing in surface and subsurface layers.

While considering the hydrological element distributions over the test-site it should be noted that there was a front in the region of 60°N to the North of the front water that was characterized by a discontinuity layer with large temperature (to 1°[illegible]$^{-1}$) and salinity (to 0.10.[illegible]$^{-1}$) gradients. Below the discontinuity layer cold (to -1.5°) brackish water (to 32.10°/oo was present. In the frontal zone to the south of St. Matthew Island a Pacific water jet with temperatures of 10-11° was observed.

Waters with unstable stratifications were observed to the south of the front. The layer of temperature increases was slight and salinity gradients were small.

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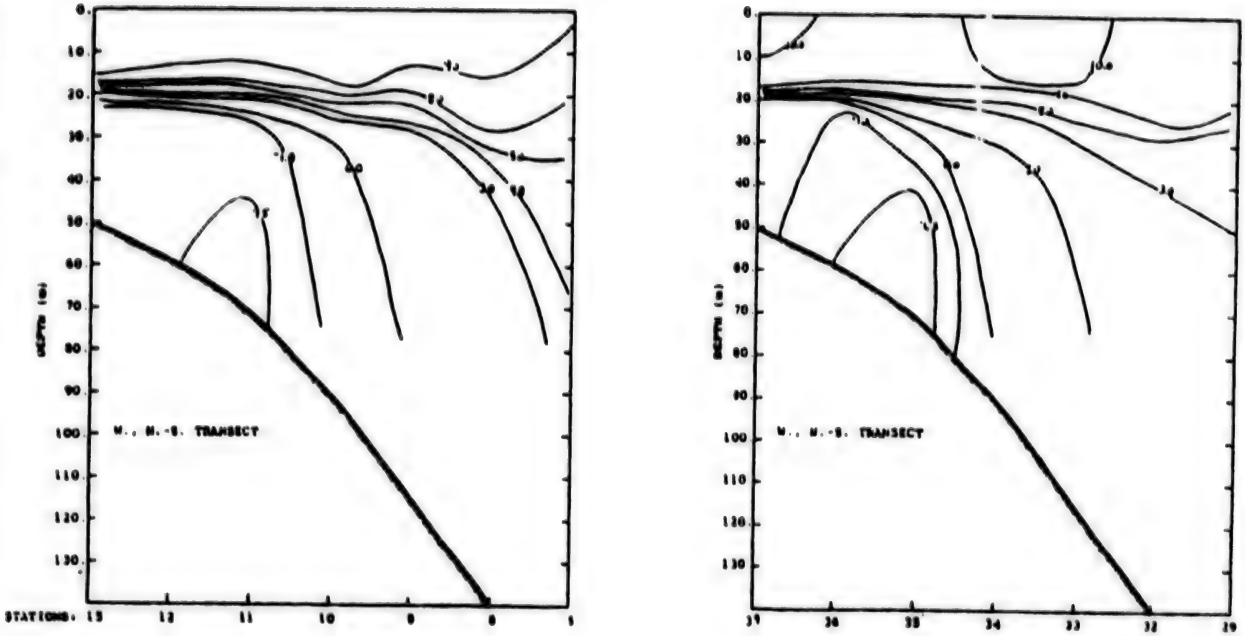

Figure 19. Temperature isopleths for the Eastern North-South (W, NW) transect.
A. Temperature (°C) isopleths developed from data of stations of first sampling.
B. Temperature (°C) isopleths developed from data of stations of second sampling.
Distance between stations is 90 km.

The distribution of temperature along the western north to south transects (sampled twice) of the sample grid is presented as isopleths in Figure 19 . The water column at each station was warmer when sampled the second time as evidenced by comparing Figures 19a and 19b. The time interval between reoccupying stations was seven to eight days. The convergence of isopleths towards the upper shelf indicates an increasingly stable thermocline in this area. The degree and vertical extent of this warming appears to be related to the stability of the associated pycnocline. The highest temperatures (1.5°C) were measured at stations with significant halo stratification which would limit thermal convection to the bottom water.

Subzero temperatures were observed in water beneath the thermocline on the shelf. Although temperatures below 75 m depth were not measured, previous investigators (Ohtani 1973; Coachran and Chamnell 1977; Muench 1976) have indicated that the cold water mass on the shelf resulted from winter cooling at this site and that water temperatures at depths below those measured off the shelf would be expected to be relatively warmed by comparison. The distribution of temperature in bottom waters from the first sampling (August 2 - August 5, 1977) can be seen in Figure 21. The cold water mass observed southwest of St. Lawrence Island was previously described (Ohtani 1973; Kitano 1971; Takenouti 1976) and appears to be a regular feature in the area.

Most of the stations on the shelf were highly thermally stratified. Station 19 (43 on the second sampling) was less thermally stratified and was isohaline, the probable result of tidal mixing at this shallow (26m) station. Muench (1976) and Ohtani (1973) suggest that winds and tidal currents are

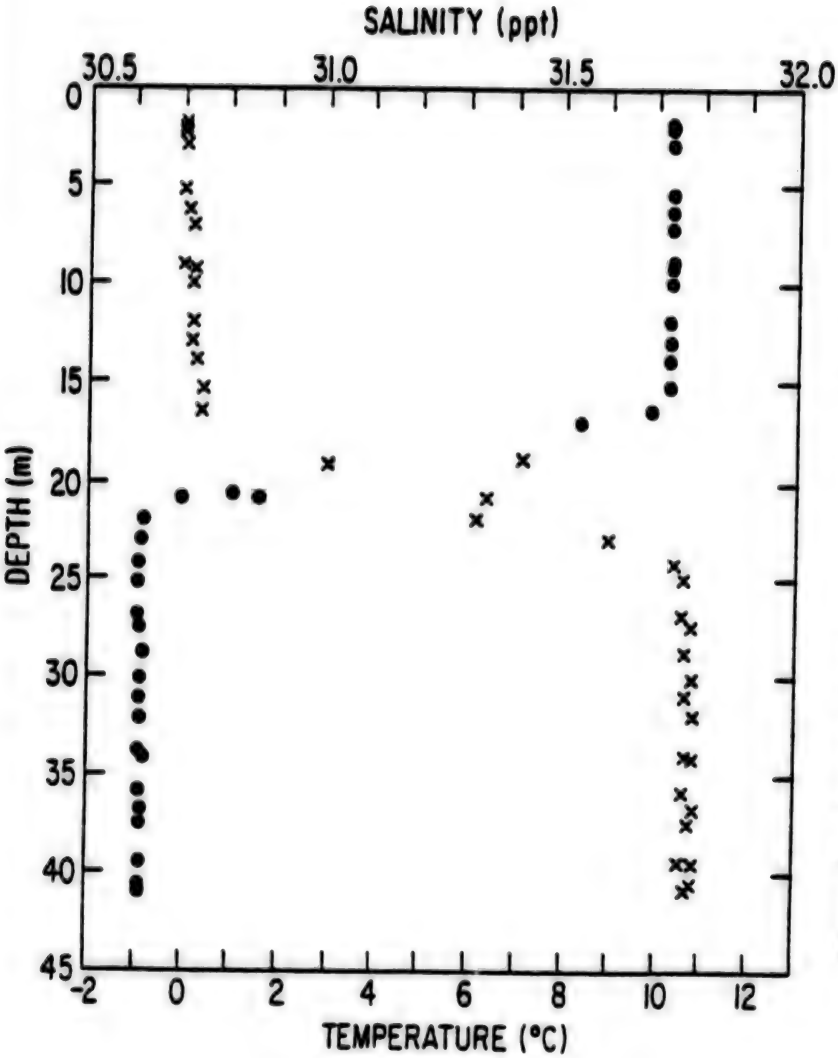

Figure 20. Salinity and temperature profiles: Station 40. Salinity (x) and temperature (0) profiles at Station 40 in the northern shelf.

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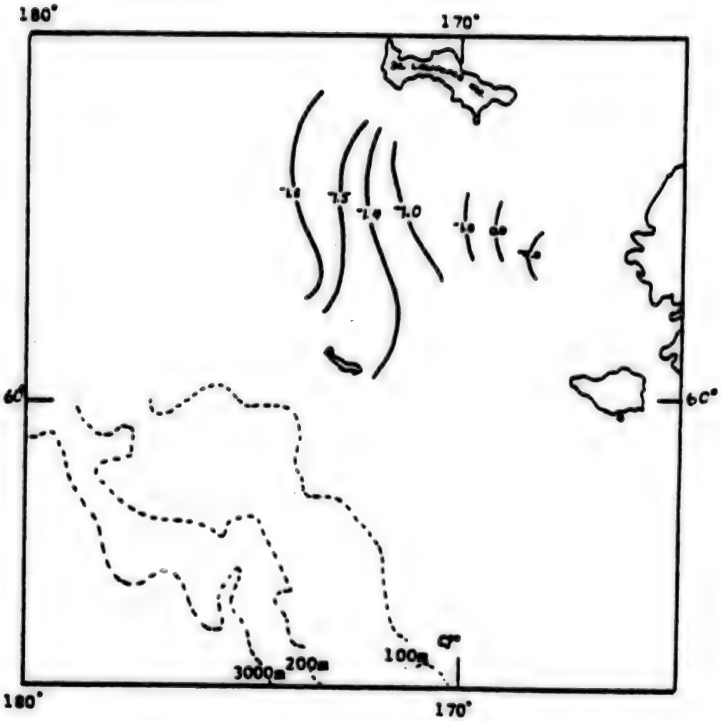

Figure 21. Bottom temperature isopleths for 80 m depths. Temperatures indicated as centigrade degrees.

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mechanisms maintaining isolhaline conditions over shallow depths on the eastern Bering Sea shelf. An illustration of the thermal and halo stratification that was observed at more northern stations, in addition to the sampling resolution of the computer-probe system, can be seen in Figure 20. At highly thermally stratified stations some minor irregularities in salinity profiles were observed in the region of the thermocline. The irregularities appear as small density inversions in sigma-t profiles. Some of these irregularities were reduced while others persisted when salinities were recalculated from temperature readings of the faster responding platinum probe and conductivity data. Although density inversions in this area have been reported (Coachman and Charnell 1977), the apparent inversions noted here are probably instrument artifacts related to the effect of rapid changes in temperature on relatively unresponsive probes. The inversions observed by Coachman and Charnell occurred in late winter in less stratified waters.

Salinity increased from north to south on both north to south transects and from east to west on the northern transect. Surface salinity isopleths appear in Figure 22. A slight increase in salinity that was generally observed upon reoccupation of stations was possibly the result of a northward component of flow. The finger-like low salinity area in the northeast section of the grid is probably the result of coastal runoff and input from Norton Sound into which the Yukon River empties.

Temperature-salinity graphs are useful in identifying water masses and mixing relationships (Dietrich 1963). Indeed, when surface and bottom

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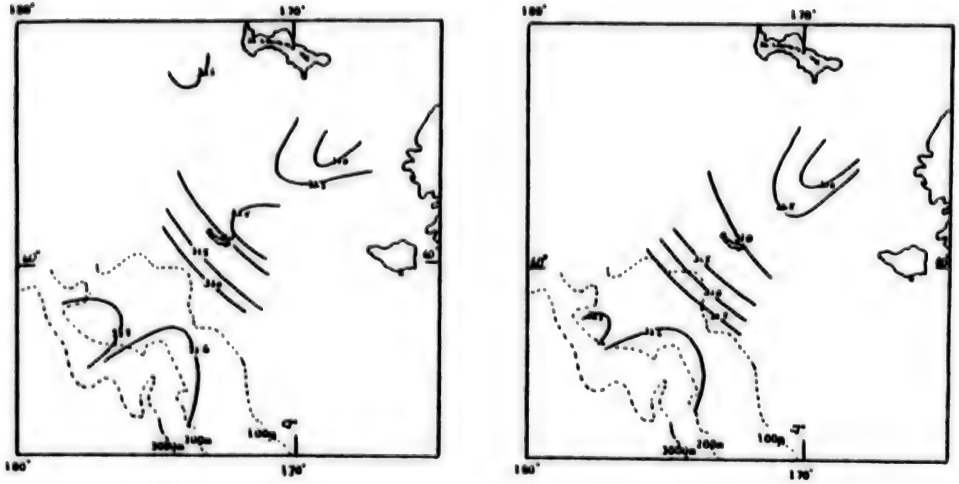

Figure 22. Surface salinity isopleths.
a) Salinity isopleths expressed as ppt developed from stations 1-24.
b) Salinity isopleths expressed as ppt developed from stations 25-48.

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Figure 23

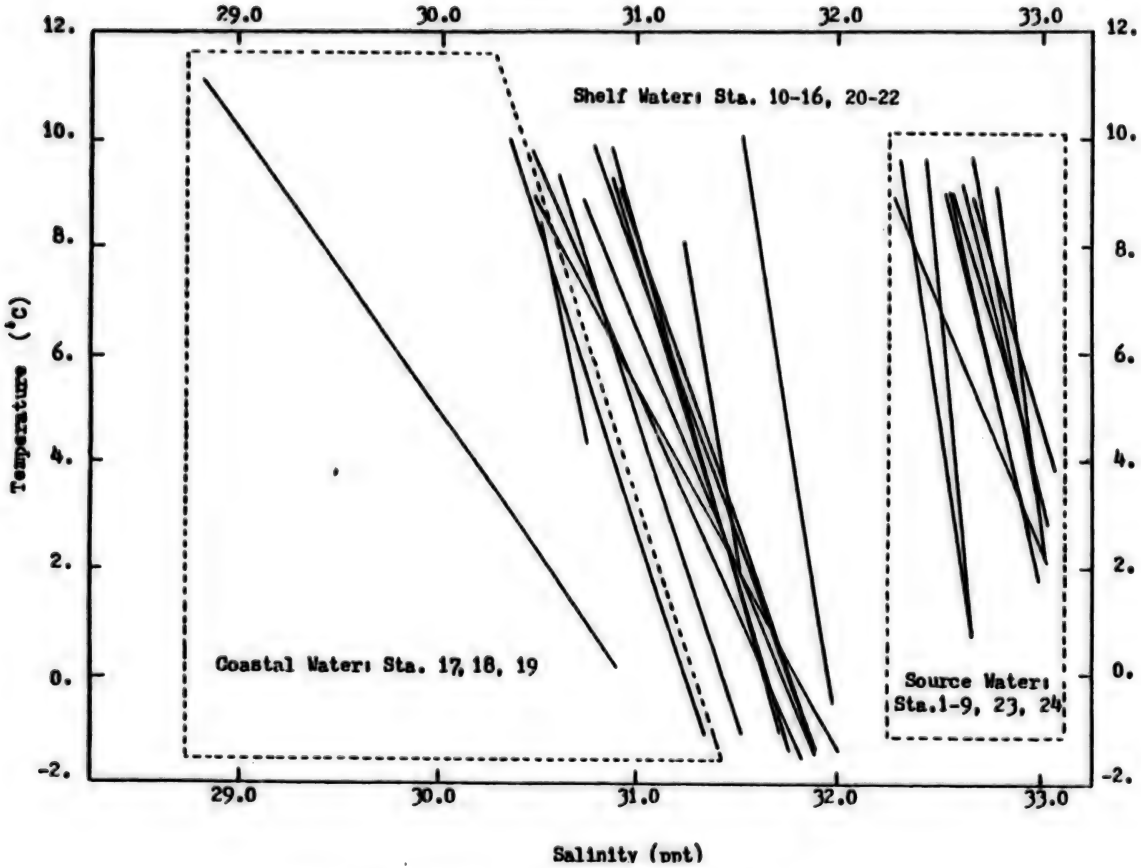

Figure 23. Salinity -temperature plot: Stations 1-24

Figure 24

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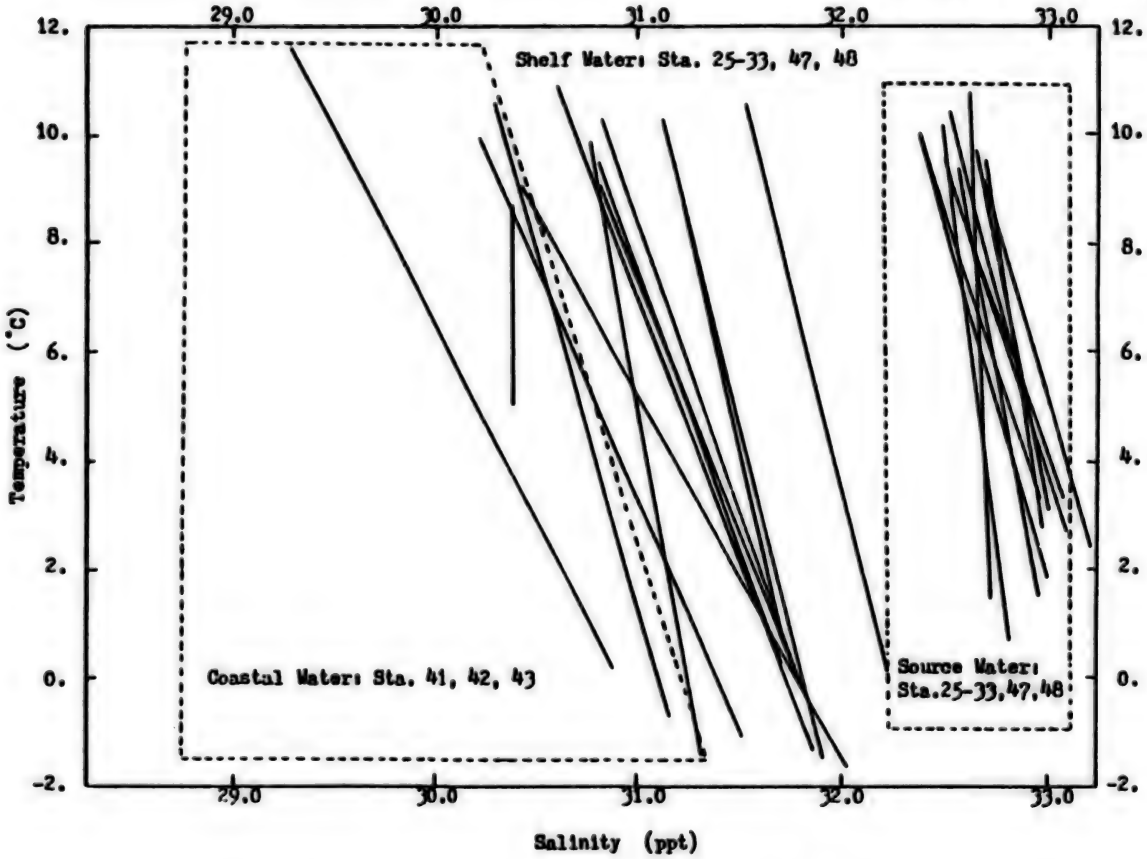

Figure 24. Salinity-temperature plot: Stations 25-48

temperature and salinity data were plotted three distinct water masses emerged. A graph of grouped surface and bottom salinities for stations 1-24 and 25-48 can be seen in Figures 23 and 24 respectively. Figures 23 and 24 show that little change in the salinity or thermal characteristics of the area occurred between reoccupation and that conditions other than steady state were not indicated. The criteria for classification of the seawater masses used here are similar to that of Takenouti and Ohtani (1974). Stations 10, 11, 12, 13, 14, 15, 16, 20, 21, 22 and their counterparts 34, 35, 36, 37, 38, 39, 40, 44, 45, 46 on the second sampling are classified here as Shelf Water having the characteristics of minor salinity stratification but strong thermal stratification. Stations 17, 18 and 19 and their counterparts 42, 43 and 44 are classified as having the characteristics of Coastal Water. The deeper coastal water stations 17 and 18 exhibit salinity as well as temperature stratification. Stations 19 and 43 are comparatively well mixed, presumably due to the shallow depth and tidal mixing which is consistent with Takenouti and Ohtani's classification of coastal water. The remaining deeper stations 1, 2, 3, 4, 5, 6, 7, 8, 9, 23, 24 will be classified as Source Water which is relatively warm by comparison to shelf water and exhibits little salinity stratification and less severe thermal stratification. A graphic representation of the location of water masses in the sampled area appears in Figure 25 .

Geostrophic Flow Estimation

The distribution of water density as sigma-t isopleths drawn from data from all transects appears in Figures 26, 27 and 28. The distribution

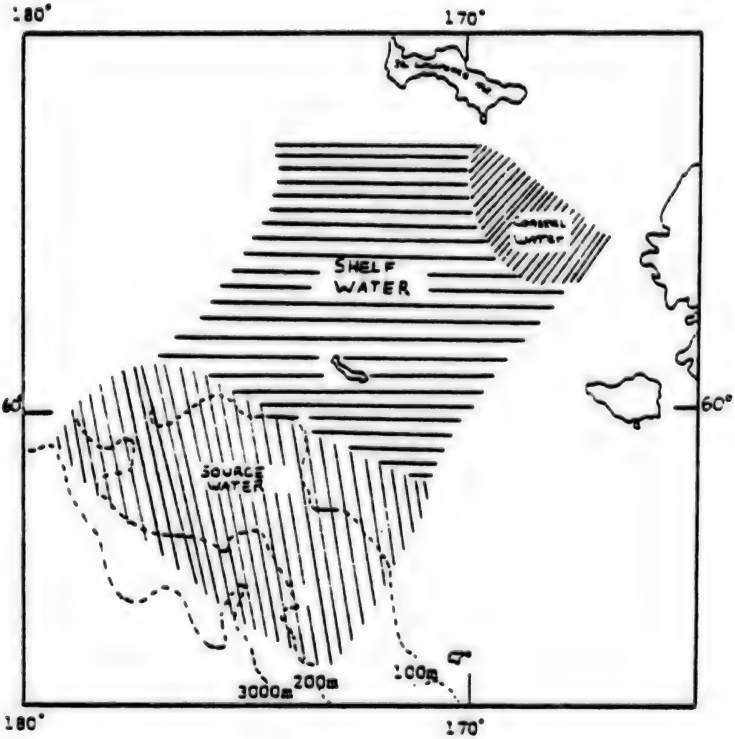

Figure 25. Location of water masses in study area. Water mass classification is based upon temperature and salinity characteristics.

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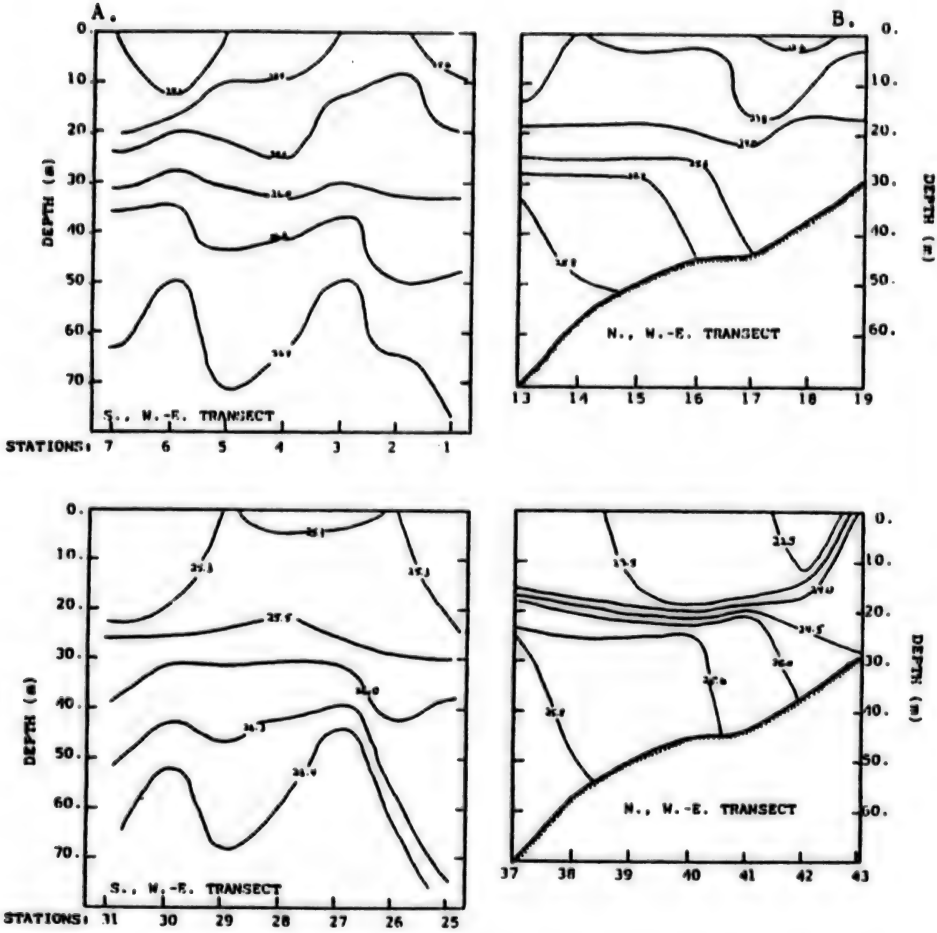

Figure. 26 Sigma-t isopleths west to east transects.

A.) Sigma-t isopleths from the southern transect along the continental slope, first sampling.

B.) Sigma-t isopleths from the northern transect, first sampling.

C.) Sigma-t isopleths from the southern transect second sampling.

D.) Sigma-t isopleths from the northern transect second sampling.

Note: West is to the left in all figures.

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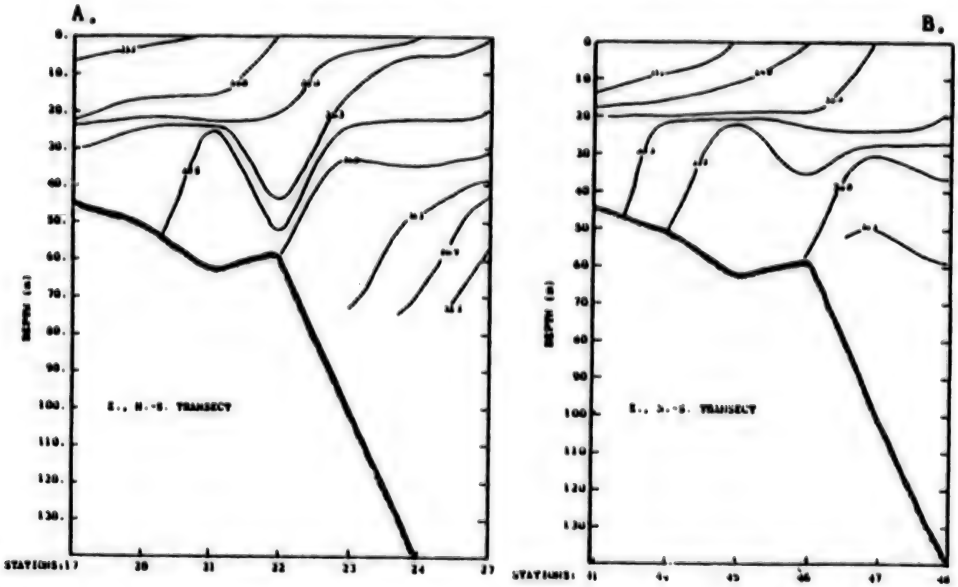

Figure 27. Sigma-t isopleths from the Western, North-South transect.
A.) Sigma-t isopleth from the first sampling. North is to the left in the figure.
B.) Sigma-t isopleths from the second sampling. North is to the left in the figure.

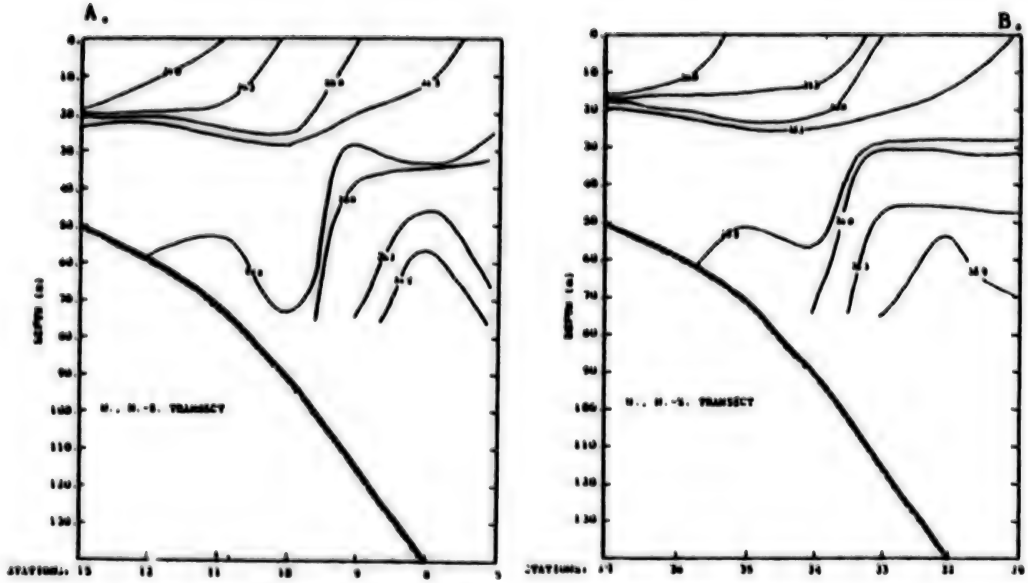

Figure 28. Sigma-t isopleths from the Eastern, North-South transects.
A.) Sigma-t isopleths from the first sampling. North is to the left in the figure.
B.) Sigma-t isopleths from the second sampling. North is to the left in the figure.

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Table 12

Anomaly of dynamic depth relative to 10, 25, 50 and 75 dbar surfaces expressed as dynamic centimenters.

STATION	10 dbar	25 dbar	50dbar	75 dbar
C1	3.64	8.58	15.37	19.98
C2	2.77	6.86	12.03	15.68
C3	2.47	6.13	10.56	13.66
1	2.68	6.47	11.43	14.95
2	2.51	6.12	11.14	14.52
3	2.53	6.15	10.76	13.94
4	2.62	6.50	11.40	14.75
5	2.61	6.43	11.25	14.76
6	2.86	6.77	11.35	14.54
7	2.72	6.67	11.39	14.71
8	2.71	6.66	11.86	15.15
9	2.89	7.08	12.13	15.74
10	3.62	8.80	14.95	19.51
11	3.89	9.35	15.17	
12	3.97	9.05	14.91	
13	4.26	9.30	14.82	
14	4.07	9.35		
15	4.21	9.69		
16	4.07	8.89		
17	4.47	10.72		
18	5.68	12.04		
19	4.13	10.02		
20	4.19	9.65		
21	4.34	10.05	15.78	

Table 12 - continued

STATION	10 dbar	25 dbar	50 dbar	75dbar
22	3.53	8.36	15.36	
23	2.95	7.36	12.30	15.99
24	2.68	6.61	11.50	14.87
25	2.92	7.25	12.54	16.22
26	2.63	6.55	12.07	15.44
27	2.68	6.62	11.27	14.33
28	2.68	6.54	11.21	14.56
29	2.65	6.59	11.35	14.71
30	2.82	6.83	12.05	15.53
31	2.76	6.83	12.05	15.53
32	2.74	6.82	11.69	14.97
33	2.91	7.07	11.88	15.25
34	3.68	8.51	14.53	18.87
35	3.77	8.95	15.00	
36	4.17	9.24	15.14	
37	4.27	9.04	14.36	
38	6.25	11.89	17.47	
39	4.06	9.36		
40	4.26	9.69		
41	4.57	10.11		
42	5.48	11.37		
43	3.82	9.21		
44	4.43	9.39		
45	4.30	9.41	15.07	

Table 12 - continued

STATION	10 dbar	25 dbar	50 dbar	75 dbar
46	3.84	8.65	14.93	
47	2.91	7.22	12.10	15.55
48	2.85	6.92	11.92	15.42

of sigma-t from the second sampling (stations 25-48) resulted in isopleths similar to those from stations 1-24 and suggests relatively stable baroclinic conditions. The isopleths in north to south planes closely resemble those prepared by Muench (1976) on a parallel transect conducted in August 1974 east of this sampling grid from Bristol Bay to Norton Sound. The convergence of isopleths towards inshore waters (Figs. 27 and 28) indicates increasingly stable pycnoclines as one moves inshore. The pycnocline is an effective barrier to vertical mixing (Cribik and Osterle 1977) and turbidity maxima associated with pycnoclines in the Bering Sea have been reported (Kawana 1975). The relationship between pycnocline stability and the vertical distribution of nutrients and chlorophyll a will be treated in a later section.

The anomaly of specific volume which was calculated from reciprocal sigma-t values shows a distribution similar to that of sigma-t. The anomaly of dynamic depth relative to isobaric surfaces was obtained by depth wise integration of the anomaly of specific volume. Inspection of the sigma-t isopleths shows that the areas of higher pressure are located at the northern end of the sampling grid. If the slope of isopycnals is negative when considering increasing depth to be positive, in the northern hemisphere, a current coming out of the page towards the reader is indicated (NYOSL 1973). Since the figures of the north to south transects (Figs. 27 and 28) have the north direction to the left, the general direction of currents indicated through the north-south planes is to the west. Through the northern west to east transect planes the direction of the current appears to be to the north (Figs.26a and 26c). The plane of the southern west to east transect (Figs.26b and 26c) is more ambiguous and may be the result of estuarine type circulation and/or upwelling.

Table 12 contains the anomaly of dynamic depth for each station relative to the 25, 50 and 75 dbar surfaces. The results of the dynamic depths calculations show that the areas of higher pressure were located in the northern and eastern areas of the sampling grid. Differences in dynamic depths relative to a given isobaric surface are typically plotted as dynamic topography (Newman and Pierson 1966; Dietrich 1963) and the reader is left to interpret direction and magnitude of geostrophic flow from a distance versus velocity plot within the figure. Such a presentation appears in the analysis of data from Bristol Bay presented by Coachman and Charnell (1977). Here, a vector field presentation relative to 25, 50 and 75 dbar surfaces in which components of geostrophic flow perpendicular to the plane of water between two stations is presented. Little real value would be obtained from the resolution of this vector field since the calculations would be overburdened with assumptions. The vector fields of calculated geostrophic flow relative to the 25, 50 and 75 dbar surfaces appear in Figures 29, 30, 31 respectively. Again, the assumption of frictionless currents should be considered when examining these figures, especially in the more northern areas where the isobaric surface is close to the bottom. These figures were constructed from data from stations C1, C2, C3, 1-24 and are quite similar to those prepared from the second sampling. The vector fields indicate the presence of a general northwesterly flow relative to the three isobaric surfaces. The velocities calculated along the continental shelf break suggest a possible estuarine type circulation where waters in surface layers move in opposite directions of lower depths. Coachman and Charnell (1977) encountered this type of circulation in Bristol Bay and suggested that the required energy for the system is supplied by winds. The entrainment of water from the lower level by the upper level is

necessary to maintain this type of circulation (Redfield et al. 1963) and hence suggests upwelling phenomena along certain sections of the continental slope. The resultant current from these vector fields probably follows the bathymetric contours as suggested by Muench (1976). The general northwest current appears to be a component of the counterclockwise gyre in the Aleutian Basin described by Takenouti and Ohtani (1974), Takenouti (1976), Ohtani (1973) and Coachman and Charnell (1977) as the effect of the Alaskan Stream entering the Bering Sea through passes in the central and eastern Aleutians.

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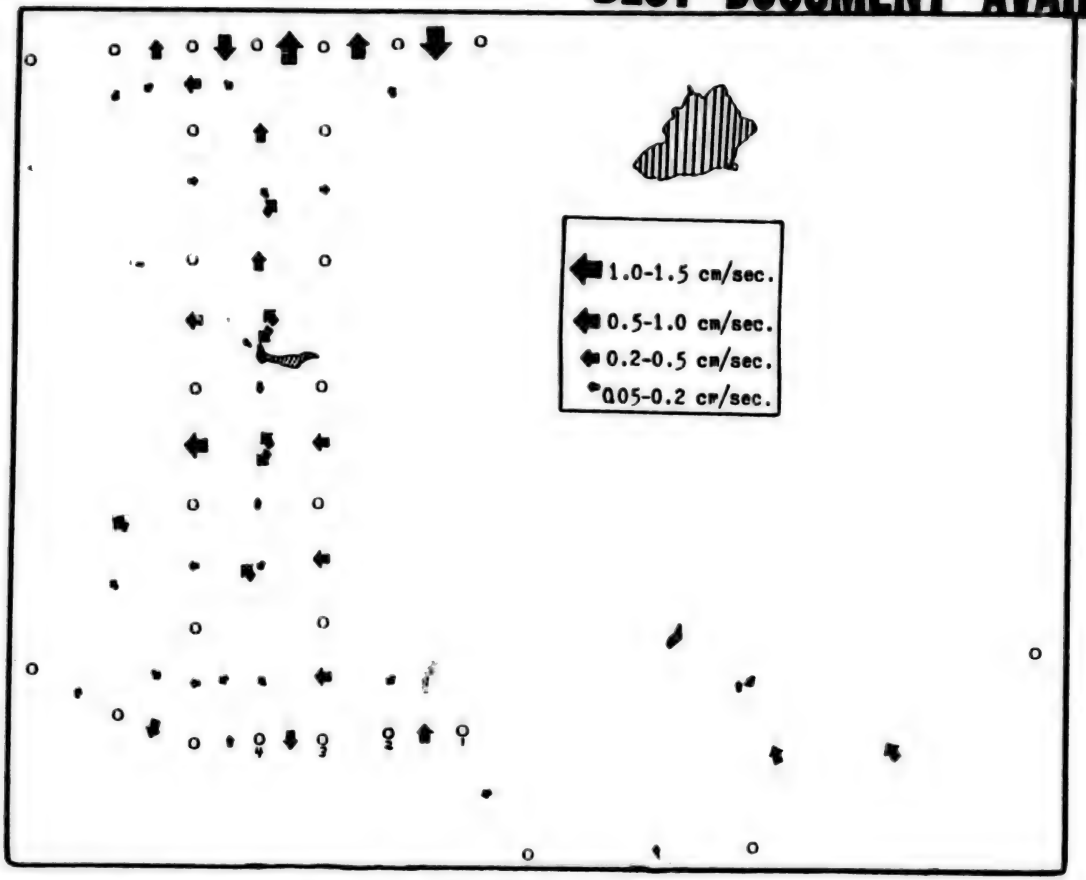

Figure 29. Geostrophic current vector field relative to the 25 dbar surface. Arrow size indicates the magnitude of the current component perpendicular to the plane formed with depth, between two stations (indicated by circles).

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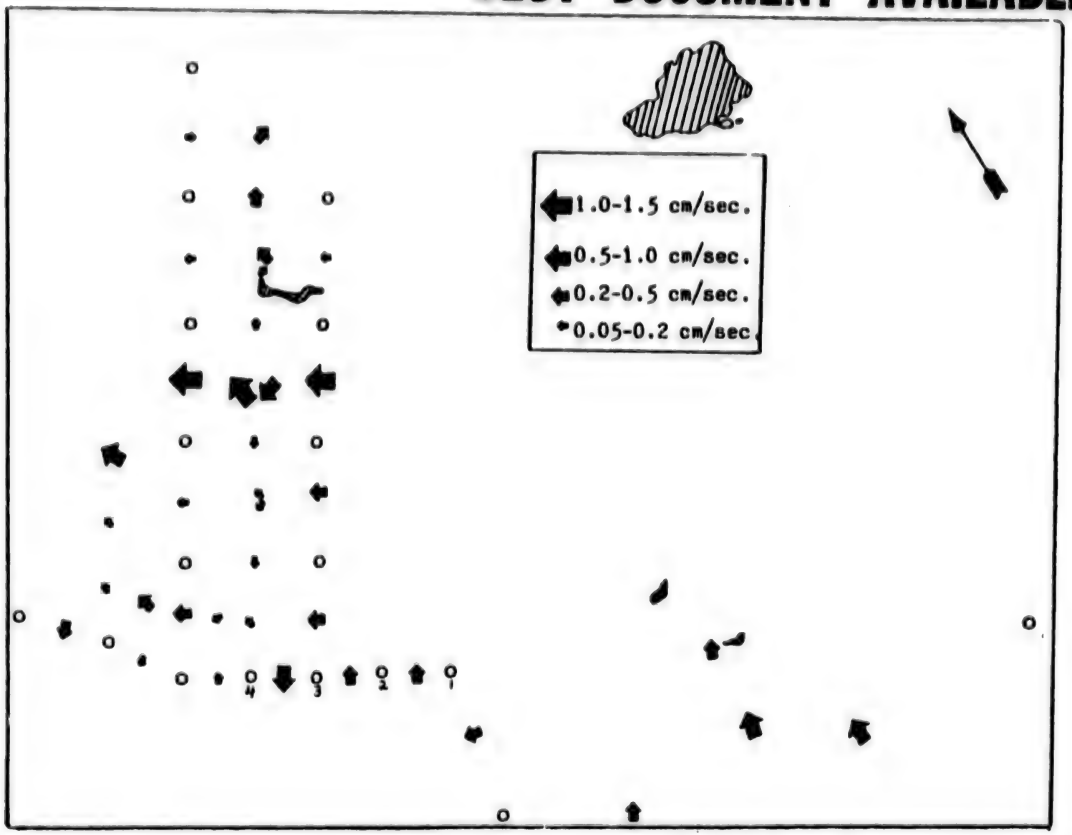

Figure 30. Geostrophic current vector field relative to the 50 dbar surface. Arrow size indicates the magnitude of the current component perpendicular to the plane formed with depth between two stations (indicated by circles).

107

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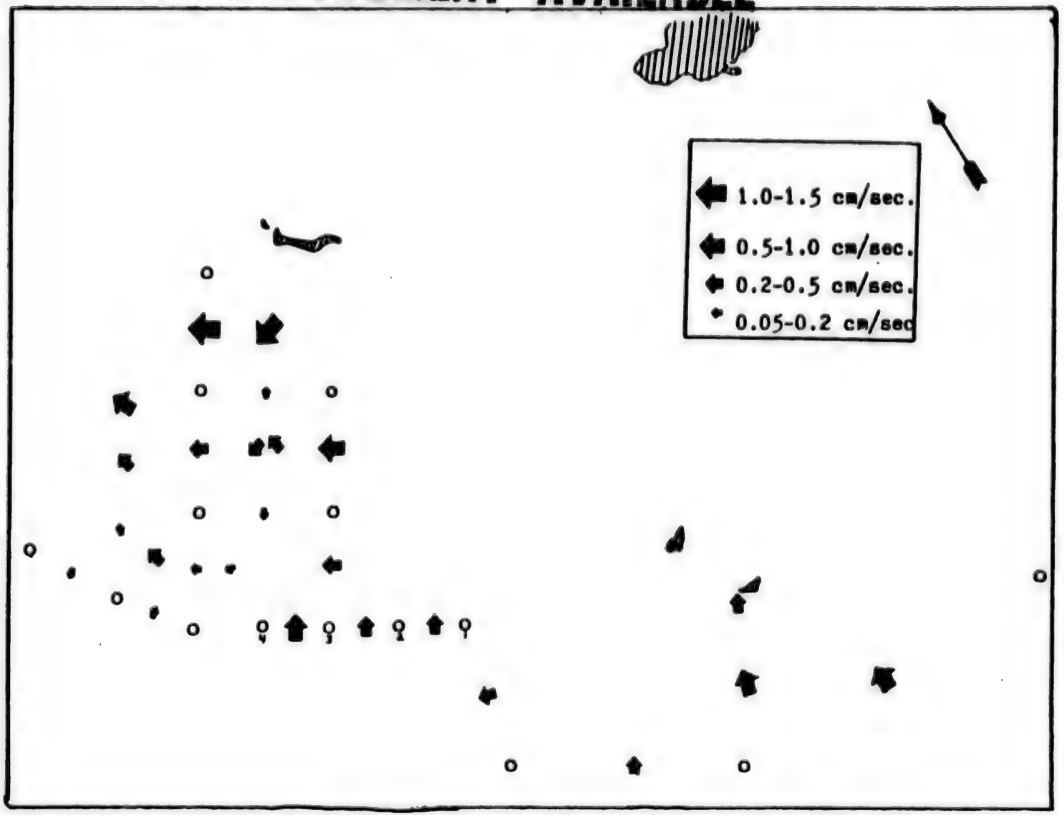

Figure 31. Geostrophic current vector field relative to the 75 dbar surface. Arrow size indicates the magnitude of the current component perpendicular to the plane formed with depth, between two stations (indicated by circles).

Light

Induced electrical currents (noises) were apparent in some light profiles taken early in the expedition. This problem may have been related to the effect of the Volna's electrical system on the unshielded photocell conductor that rested upon the vessel's metal afterdeck. This problem was solved by routing the signal from the submarine photocell through the turbidity conductor of the Interocean 513D probe package, thus sacrificing the turbidity probe. Profiles that were judged to be unacceptable based on obvious voltage irregularities were omitted from the calculation of extinction coefficients which appear in Table 13. The largest white extinction coefficients (on the order of $0.15 m^{-1}$) were associated with the coastal water mass in the northern section of the sampling grid. Source water had the lowest values ($0.07 m^{-1}$) and shelf water had generally intermediate values ($0.10 m^{-1}$).

In the marine environment suspended particles generally reduce light transmission by 30-70% in coastal waters while less than 7% along the continental shelf (Clarke and Denton 1962). Kawana (1975) in a study of the summer distribution of turbidity in the Bering Sea made similar observations. The possible source of turbidity to the coastal water area includes biological particles, detrital and inert solids input from land drainage and from resuspension of sediments as a result of tidal flow at shallow depths. Regression analysis failed to substantiate a significant

Table 13

Observed light extinction coefficients (m^{-1})

	Light Quality			
Station	White	Green	Blue	Red
1	.08	.11	.11	.29
2	.08	.07	.08	.35
3	—	NOISE	—	—
4	.08	.06	.07	.26
5	.08	.08	.08	.30
6	.09	.10	.11	.33
7	.11	.10	.11	.35
8	.11	.09	.10	.29
9	.12	.13	.15	.32
10	NOISE	NOISE	NOISE	NOISE
11	NOISE	NOISE	NOISE	NOISE
12	NOISE	NOISE	NOISE	NOISE
13	NOISE	NOISE	NOISE	NOISE
14	NOISE	NOISE	NOISE	NOISE
15	.07	.09	.09	
16	.04	.01	.07	
17	.11	.10	.13	
18	.16	.13	.16	
19	—	DARK	—	
20	.16	.14	.15	
21	.11	.10	.11	

Table 13 - continued

Light Quality

Station	White	Green	Blue	Red
22	.12	.09	.13	
23	.13	.10	.11	
24	.07	.06	.07	
25	.21	.08		
26	.12	.15	.17	
27	.07	.07	.06	
28	.10	.09	.08	
29	.06	.06	.07	
30	.06	.07	.07	
31	—	DARK	—	
32	.10	.09	.11	
33	.07	.05	.09	
34	.09	.09	.11	
35	.10	.10	.10	
36	.14	.12	.13	
37	.11	.09		
38	.08	DARK	—	
39	—	DARK	—	
40	.13	.11	.11	
41	.15	.12	.14	
42	.15	.12	.14	

Table 13 - continued

Light Quality

Station	White	Green	Blue	Red
43	.14	.10	.13	
44	.05	.09	.10	
45	.13	.12	.13	
46	.11	.10	.10	
47		DARK		
48	.10	.09	.11	

NOISE* indicates readings eliminated from calculations due to evidence of induced current in voltage profiles. DARK indicates station where photocell voltages were considered too small due to darkness for accurate calculations.

relationship ($p < 0.05$) between light extinction coefficients for the different light qualities and surface or depth averaged chlorophyll values.

Ambient light levels recorded from the photometer's reference cell on the deck of the Volna appear in Figure 32. A reading of at least 1,200 ft-c was recorded each day of the expedition. The maximum recorded intensity was 3,000 ft-c.

McRoy and Goering (1976) found that light generally limits phytoplankton development in the Bering Sea. The relationship between the euphotic zone depth and pycnocline depth plays an important role in the annual cycle of phytoplankton production in the Bering Sea (McRoy and Goering 1976). High winds typical of this area (N.O.A.A. 1977) result in strong mixing above the thermocline. Generally, the phytoplankton population increases when the upper mixed layer is shallower than the critical depth (Hood and Kelly 1974; McRoy and Goering 1976). Euphotic zone depths were calculated using the 10% light depth (Odum 1971). At all stations the surface mixed layer was shallower than the euphotic zone depth. Generally the depth of the euphotic zone and the surface mixed layer increased (approximately doubled) towards the continental shelf (Fig. 33).

Chemical

1) Water

Temperature, salinity, dissolved oxygen and nutrient data collected during the expedition are listed in the appendix B.

Oxygen

The oxygen content of the surface layer is determined through the interaction of the water mass with the atmosphere. Processes of gas adsorption and desorption are influenced by such hydrological characteristics as temperature and salinity. For the summer period when the water temperature is appreciably increased the decrease of both absolute and relative oxygen content would seem natural. However, in a given region (Figs. 34, 35, 36) the absolute oxygen content varied within the range 7.0 ml/l to 7.5 ml/l at temperatures 9°, salinity 32.7-32.9°/oo and the percent saturation exceeded 100%. This phenomenon is attributed to phytoplankton development in the summer period.

Fig. 34 shows the vertical and horizontal distribution of oxygen In the northern sections the oxygen content of the water column was significantly higher (8.0-9.0 ml/l) due to the shallower depth vertical mixing and decreased salinity (0.5-31.5°/oo).

Maximum oxygen concentrations (9-11 ml/l) were present near stations 12-15 (Fig. 35) and the percent saturation was 12.0°/oo.

Nutrients

The distribution of phosphate, nitrite, nitrate and silica is shown in Figs. 37 - 41.

Silicon (Figs. 39-41) generally varied within the range 200 ug/l to 5000 ug/l. In the surface layer where enhancement of biological productivity is generally observed, the uptake of the various forms of silicon is active which lead to its substantial decrease. Due to the solution of silicon rocks, destruction and sinking to the bottom of various organisms containing silica, silicate storage with depth takes place. Maximum silicon content 6000 ug/l was observed at 2500 m depth, profile (Station 1-7 Fig. 39).

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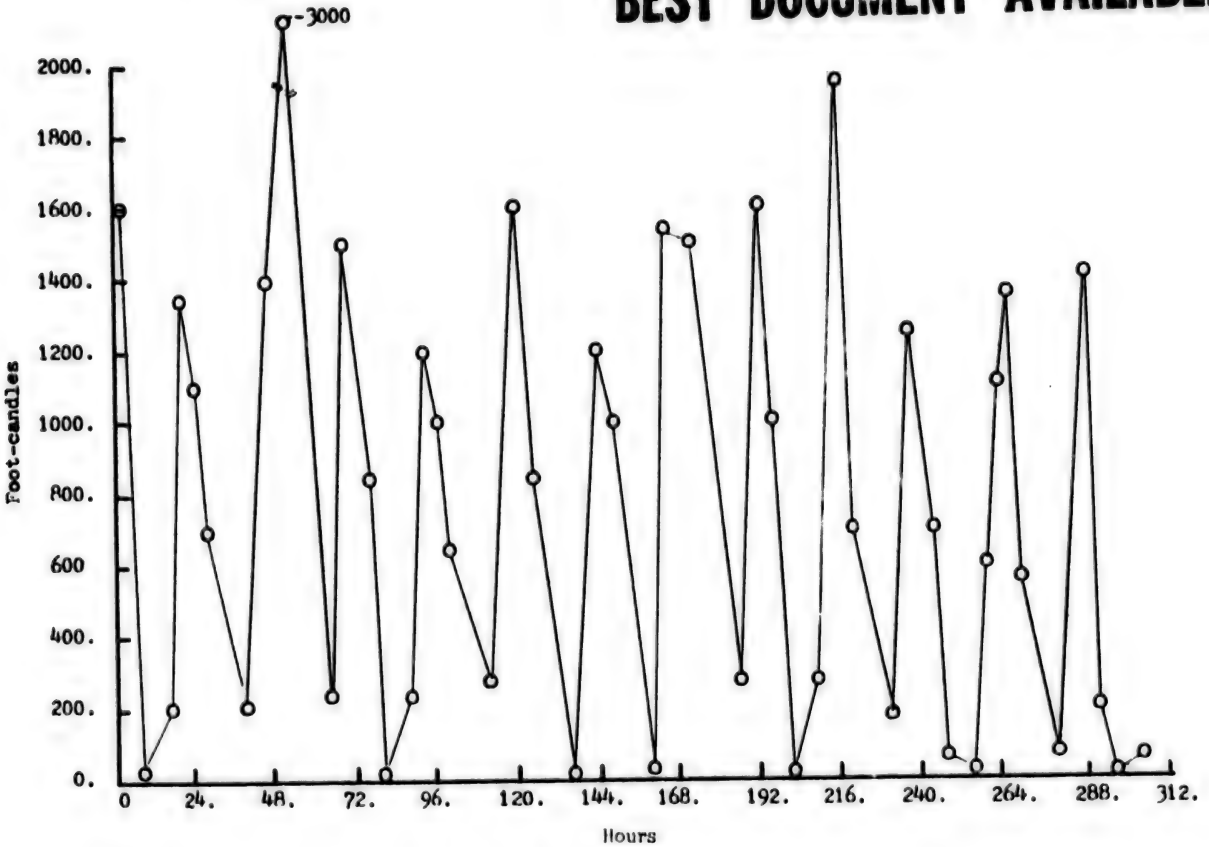

Figure 32. Ambient light intensity at station.
Ambient light intensity (as foot candles) recorded by a photometer reference cell and time (hours) from the start of the day (GMT) that station I was sampled.

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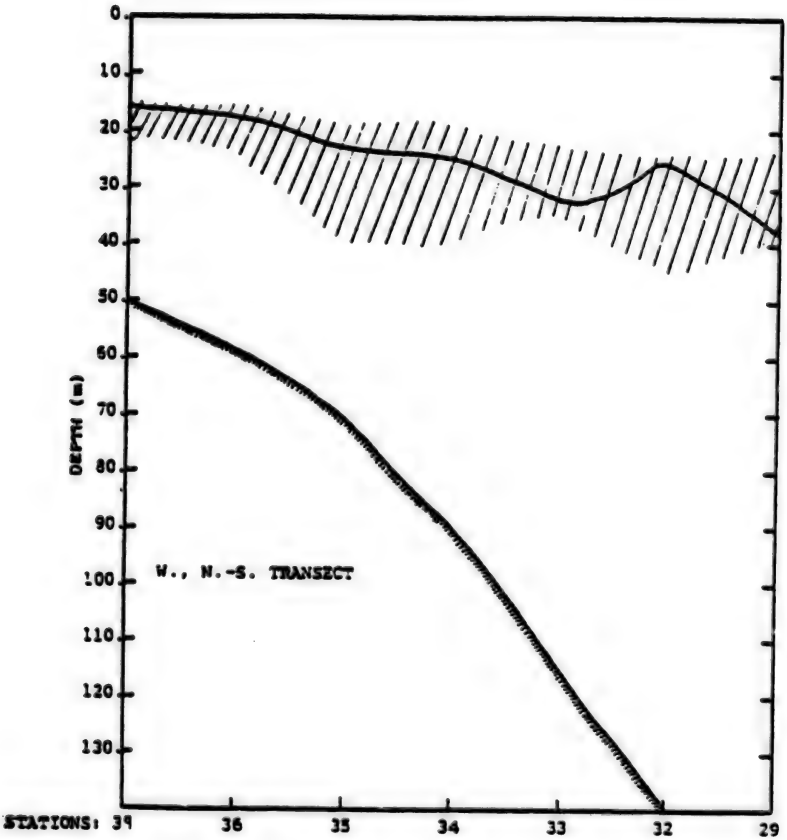

Figure 33. Mixed layer - euphotic zone relationship on a north to south transec Mixed layer is indicated as the water above the thermocline (shaded area). Solid line indicates the depth of the euphotic zone.

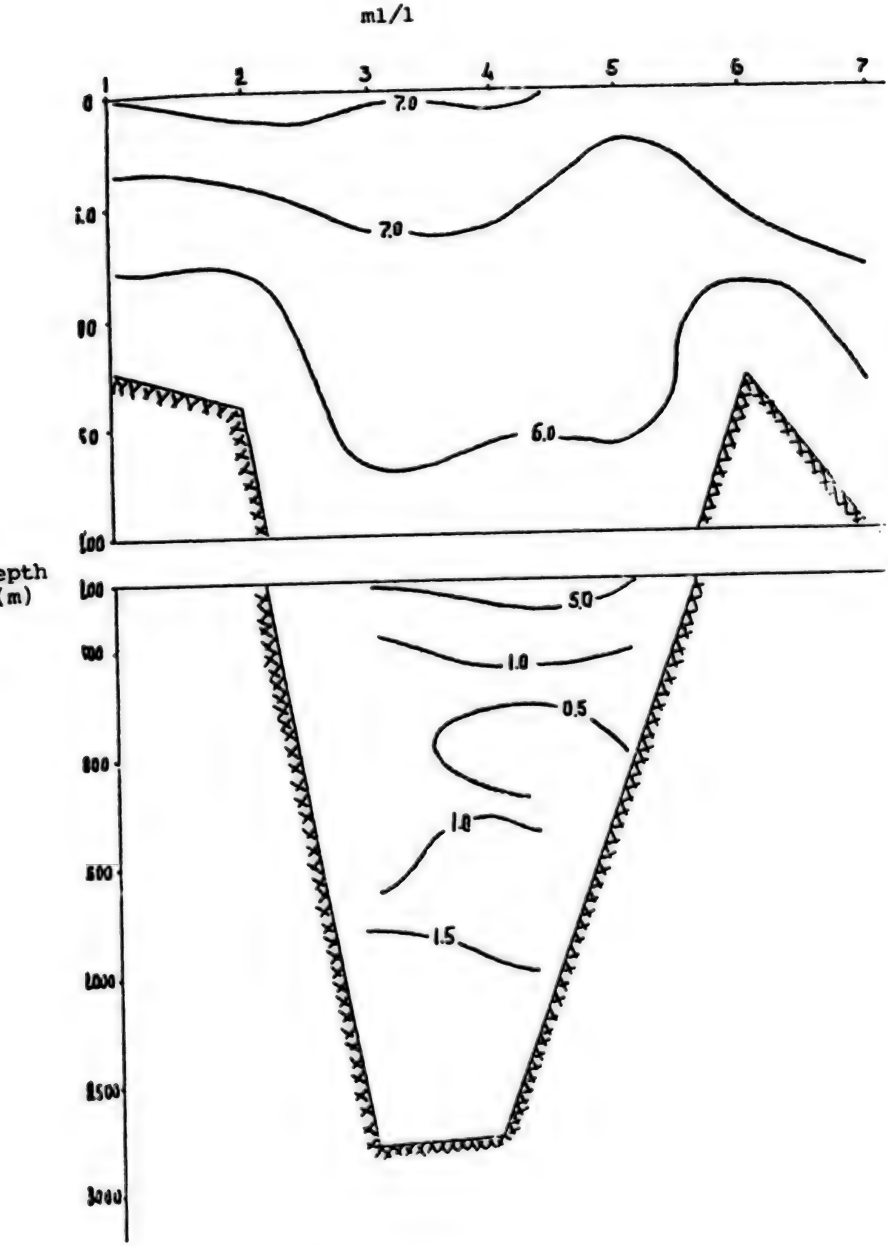

Figure 34. Distribution of oxygen (ml/l) along Transect No. 1

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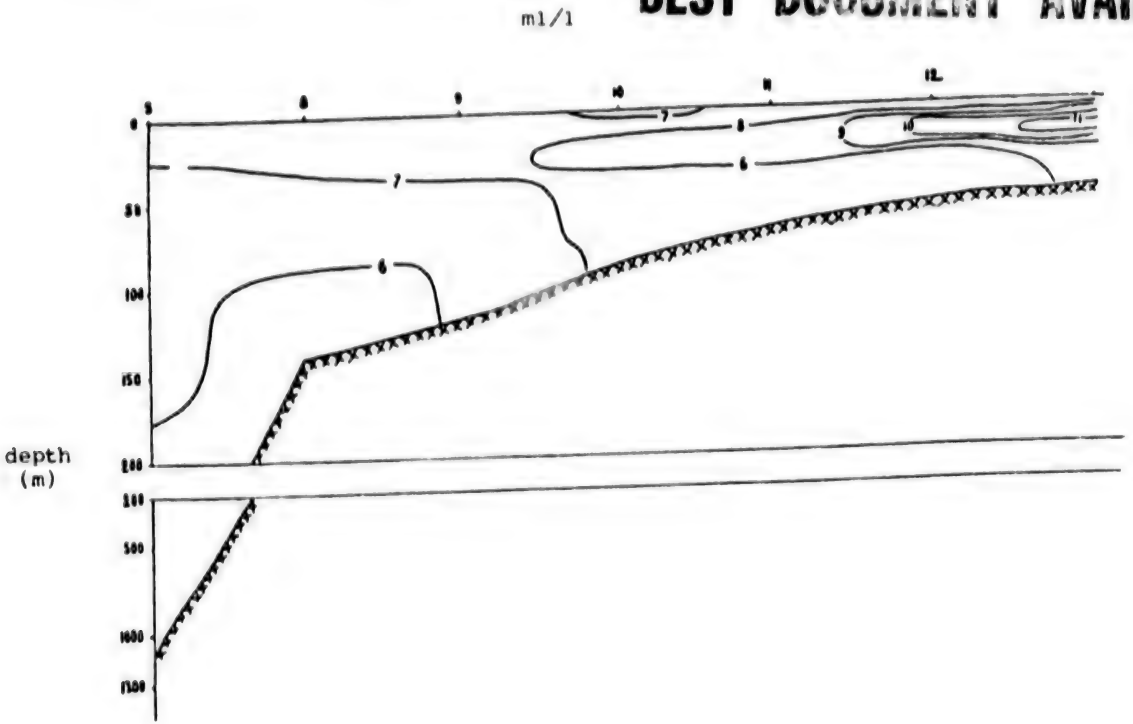

Figure 35. Distribution of oxygen (ml/l) along Transect No. 2

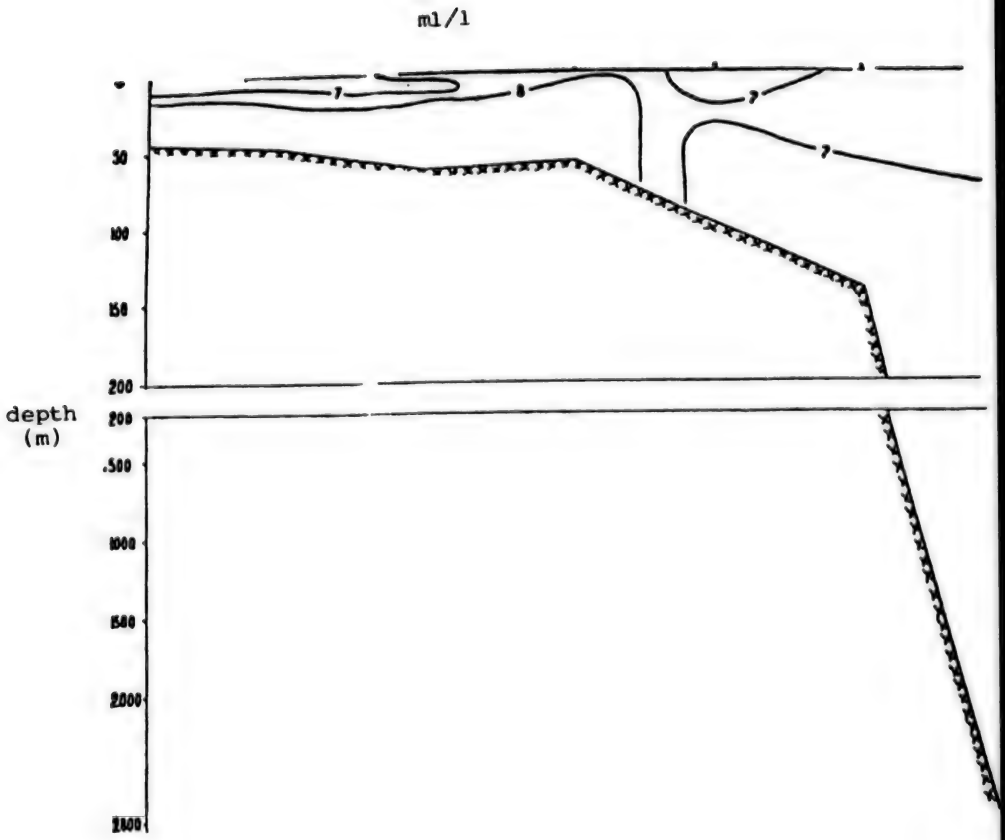

Figure 36. Distribution of oxygen (ml/l) along Transect No. 4

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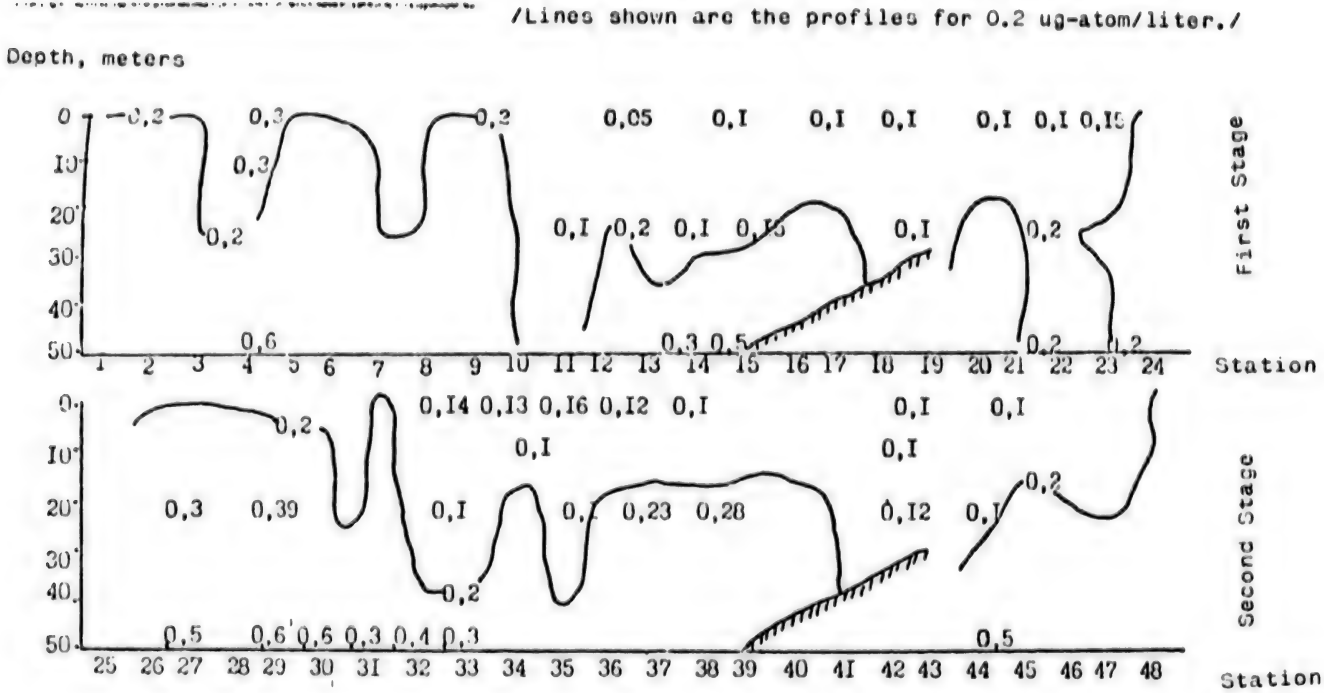

Figure 37. Spatial distribution of nitrites, in micrograms-atoms per liter, on the /study/ polygon in the Bering Sea.

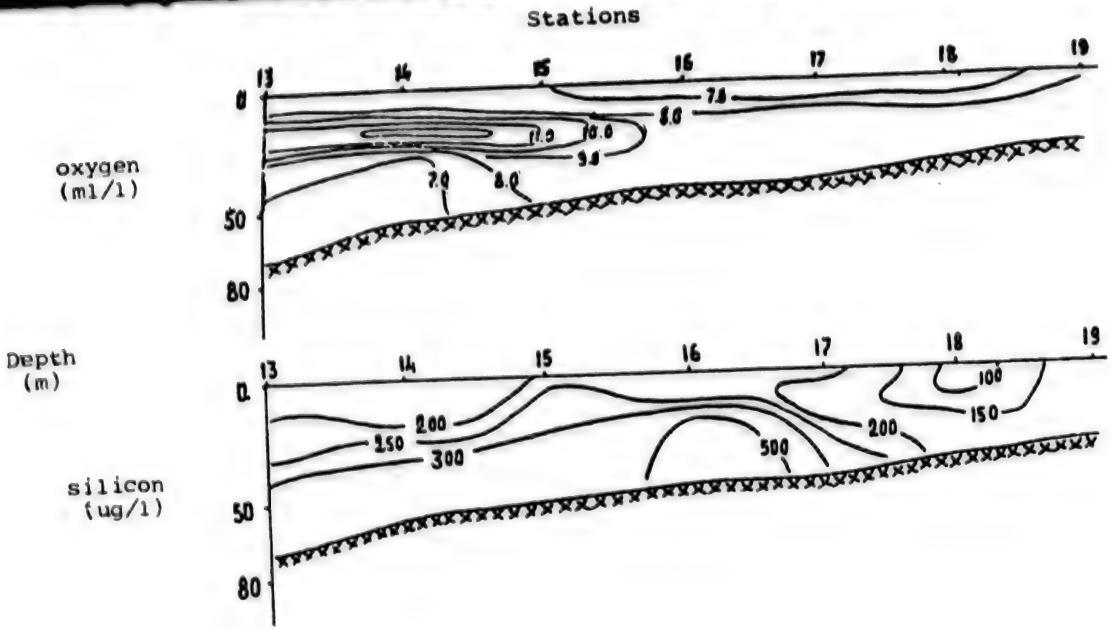

Figure 36. Distribution of oxygen (ml/l) and silicon (ug/l) along Transect no. 3

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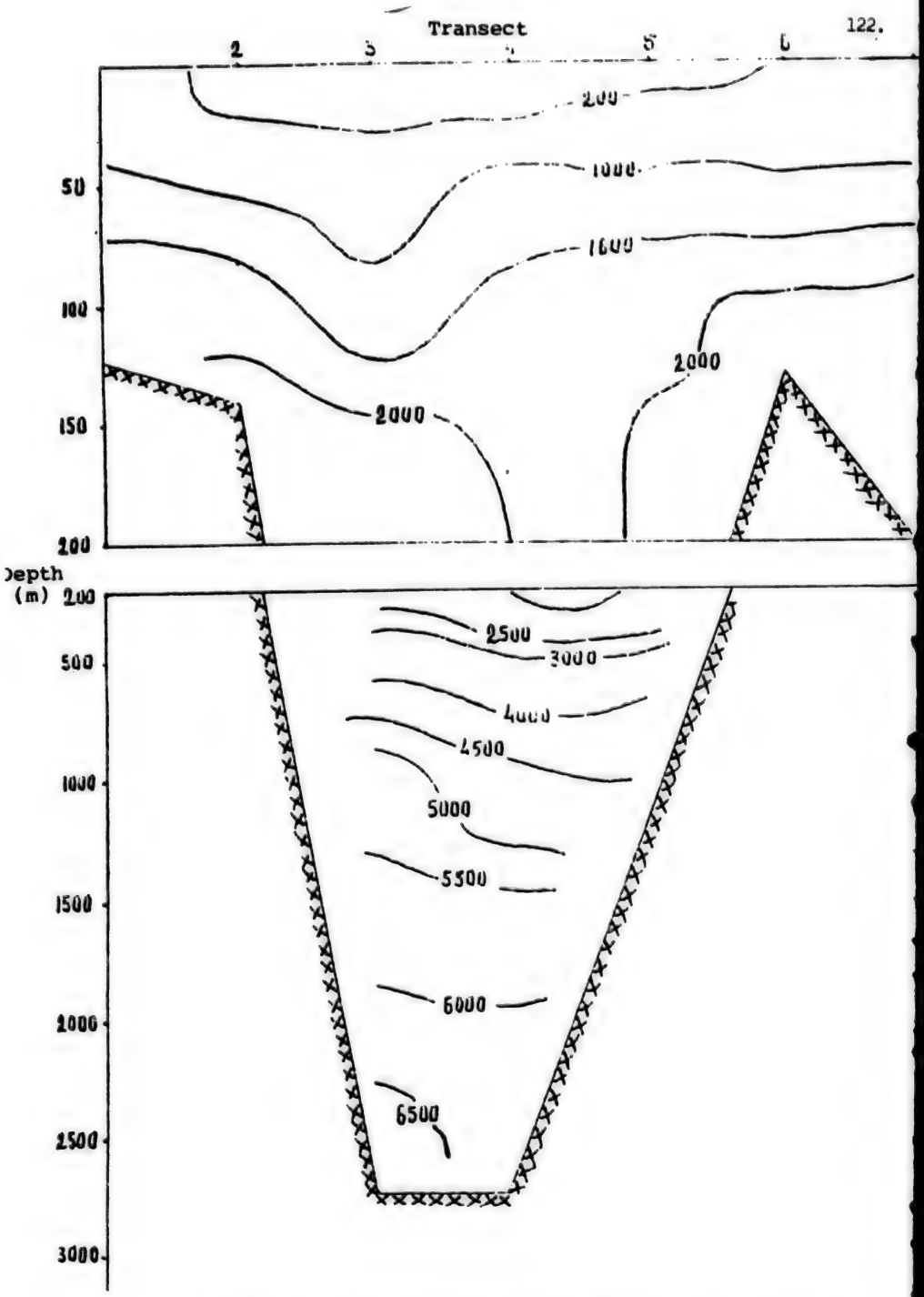

Figure 39. Distribution of silicon (ug/l) along Transect No. 1

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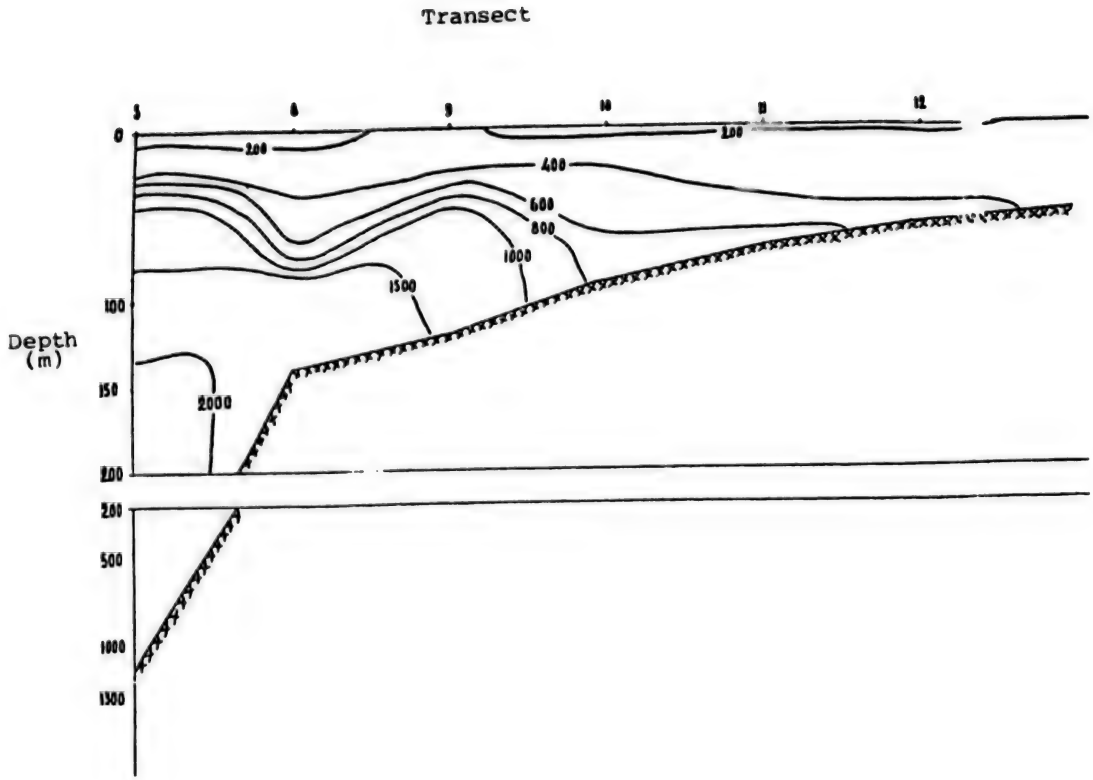

Figure 40. Distribution of silicon (ug/l) along Transect No. 2

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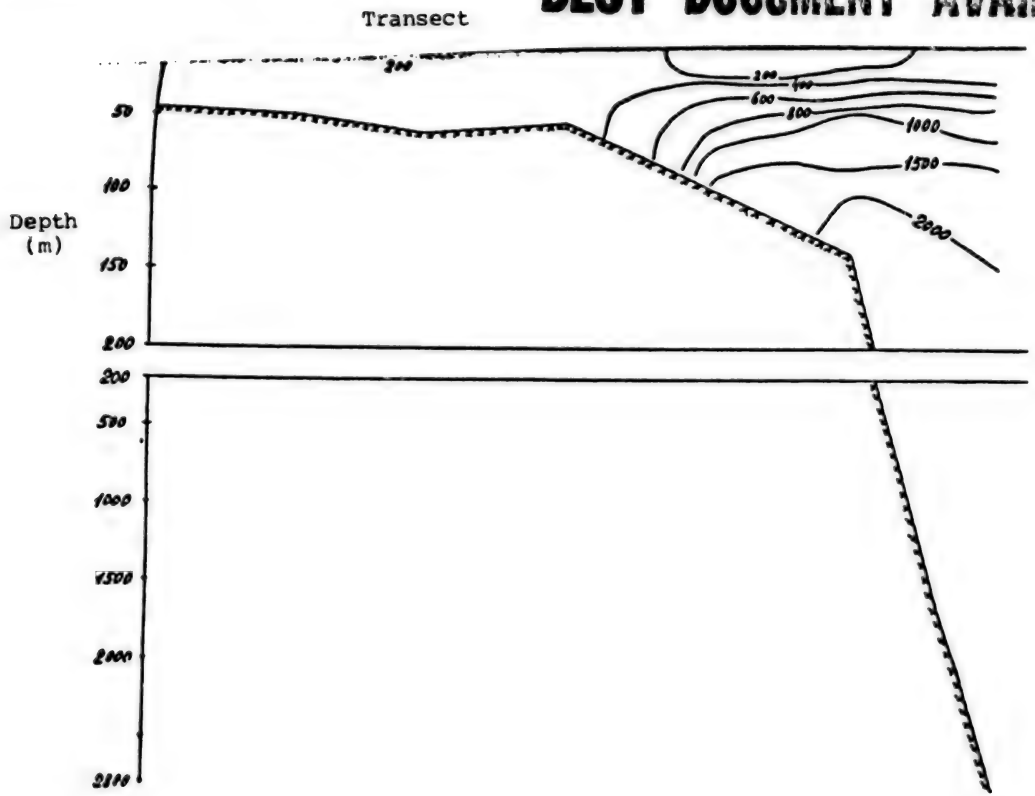

Figure 41. Distribution of silicon (ug/l) along Transect No. 2

The distribution of phosphate, silicates, nitrate and total inorganic nitrogen as the sum of NH_3, NO_2, and NO_3 all exhibited strong vertical and horizontal (in the north-south direction) gradients. The impact of primary production on the distribution of these nutrients became evident in changes in nutrient profiles upon reoccupation of stations, while the physical characteristics of the first twenty-four stations closely resembled stations 24-48, respectively. The temporal changes will be considered in later sections while their spatial distribution is considered first.

The greater mass of inorganic nitrogen was found as nitrate over the entire sampling area. The distribution of total inorganic nitrogen resembles that of nitrate. Vertical isopleths of nitrate for all transects (Figs.42, 43, 44) illustrate strong vertical and horizontal gradients. The ultimate source of nitrogen to the shelf area appears to be the source water just below the shelf as indicated in the figures from the first twenty-four stations of vertical isopleths along both north to south transects. Concentrations of NO_3 greater than 50 ug at/l were associated with water below the thermocline at stations along the continental shelf break. Effective nitrate depletion (1. ug-at NO_3/l) was observed in the relatively warm water above the thermocline at the northern shelf water stations. The proportion of total inorganic nitrogen as ammonia and nitrite increases concurrent with a decrease in total inorganic nitrogen as distance from the source water area increases and indicates

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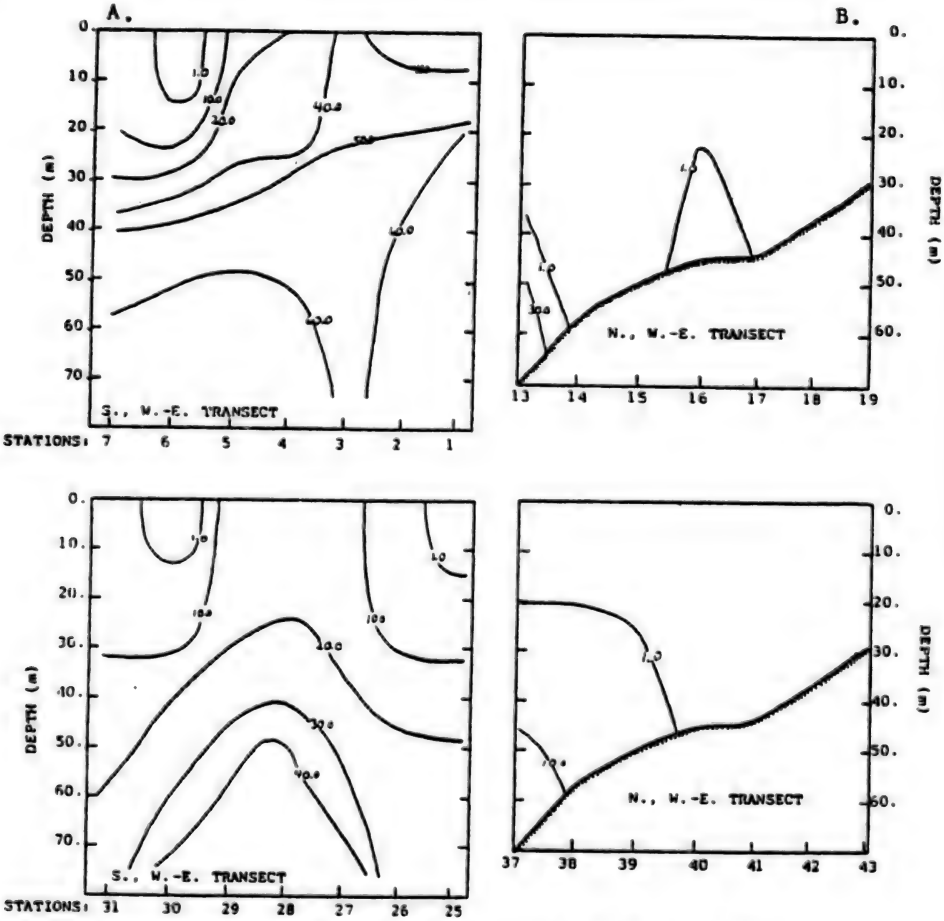

Figure 42. Nitrate isopleths from northern and southern transects.

a) Nitrate (as ug-at/l) isopleths from the southern transect's first sampling.

b) Nitrate (as ug-at/l) isopleths from the northern transect's first sampling.

c) Nitrate (as ug-at/l) isopleths from the southern transect's second sampling.

d) Nitrate (as ug-at/l) isopleths from the northern transect's second sampling.

Note: West is to the left in all figures.

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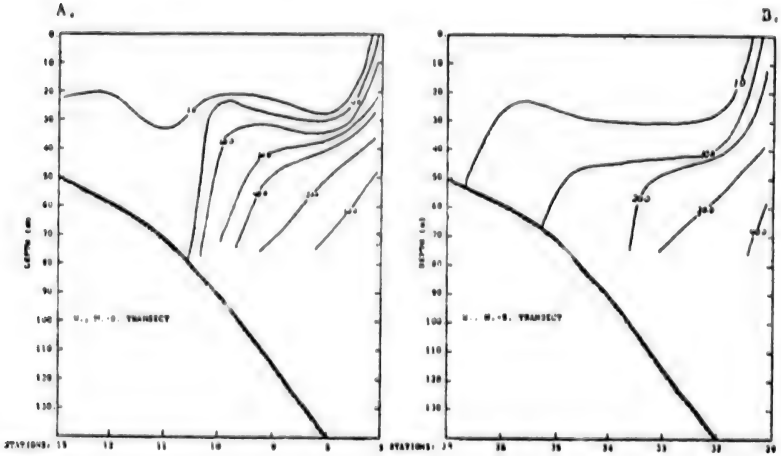

Figure 43. Nitrate isopleths from the western transects.
a) Nitrate (as ug-at/l) from the western transect's first sampling. North is to the left in figure.
b) Nitrate (as ug-at/l) from the western transect's second sampling. North is to the left in figure.

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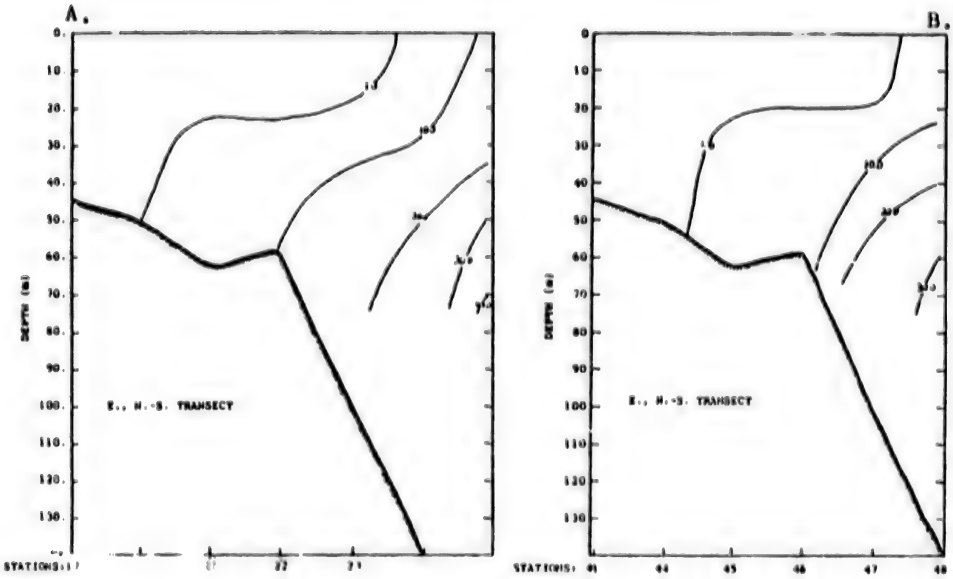

Figure 44. Nitrate isopleths from the eastern transects.
a) Nitrate (as ug-at/l) isopleths from the eastern transect's first sampling. North is to the left in figure.
b) Nitrate (as ug-at/l) isopleths from the eastern transect's second sampling. North is to the left in figure.

that nitrogen cycling would be a mechanism of greater importance than advection of nitrogen at northern shelf stations for sustaining summer productivity. Ammonia values ranged from 1. ug-at/l to 7. ug-at/l. Nitrite values greater than 1 ug-at/l were recorded in only two samples from depths below the thermocline at stations along the continental shelf break. Total inorganic nitrogen concentrations less than 1 ug-at/l characterized stations along the eastern section of the northern transect and exhibited little vertical gradients.

The effect of the pycnocline on the vertical distribution of nutrients is evident in the nitrate isopleths. Vertical stratification is more severe in the northern section of shelf water and probably presents a barrier to nutrient renewal from bottom waters into the euphotic zone. However, advective and diffusive processes could be expected to supply inorganic nitrogen to the euphotic zone in the less thermally stratified area of source water and the lower shelf area.

The distribution of phosphate resembles that of nitrate in isopleths along the southern, northern and western transects from the first samplings (Figs. 45 and 46). Total inorganic nitrogen and phosphate concentrations were highly correlated ($r=.80$, 217df $p < .001$). Again the isopleths indicate that the ultimate source of this nutrient is the area of source water at the southern end of the sampling area. Phosphate values ranged two orders of magnitude over the sampled area (0.1 ug-at/l -10. ug-at/l). The range of total inorganic nitrogen values as the sum of NH_3, NO_2 and NO_3 included four orders of magnitude (0.6 ug-at/l-130. ug-at/l). A geometric mean linear regression of total inorganic nitrogen

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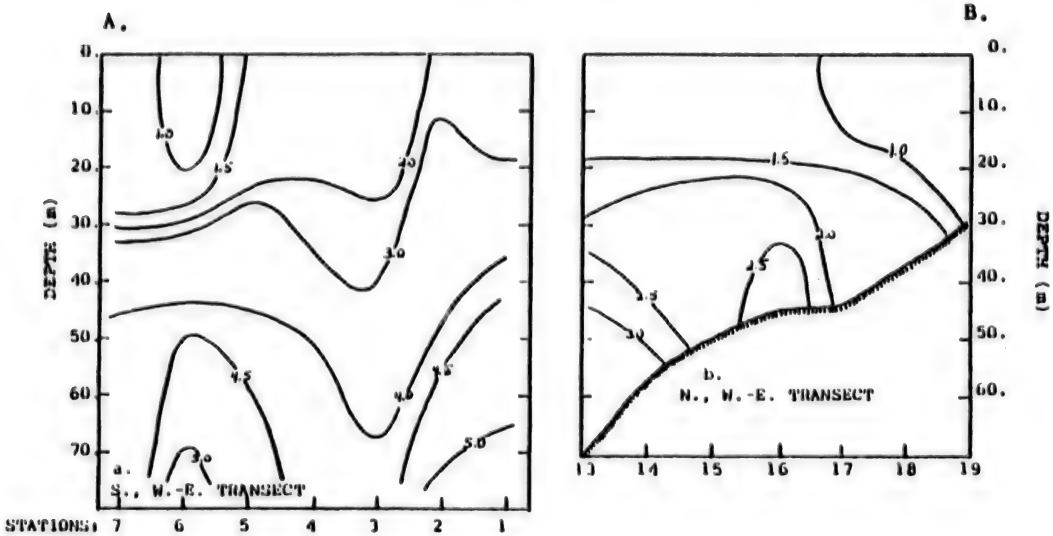

Figure 45. Phosphate isopleths from northern and southern transects.
a) Phosphate (as ug-at/l) isopleths from southern transect's first sampling. West is to the left in the figure.
b) Phosphate (as ug-at/l) isopleths from northern transect's first sampling. West is to the left in the figure.

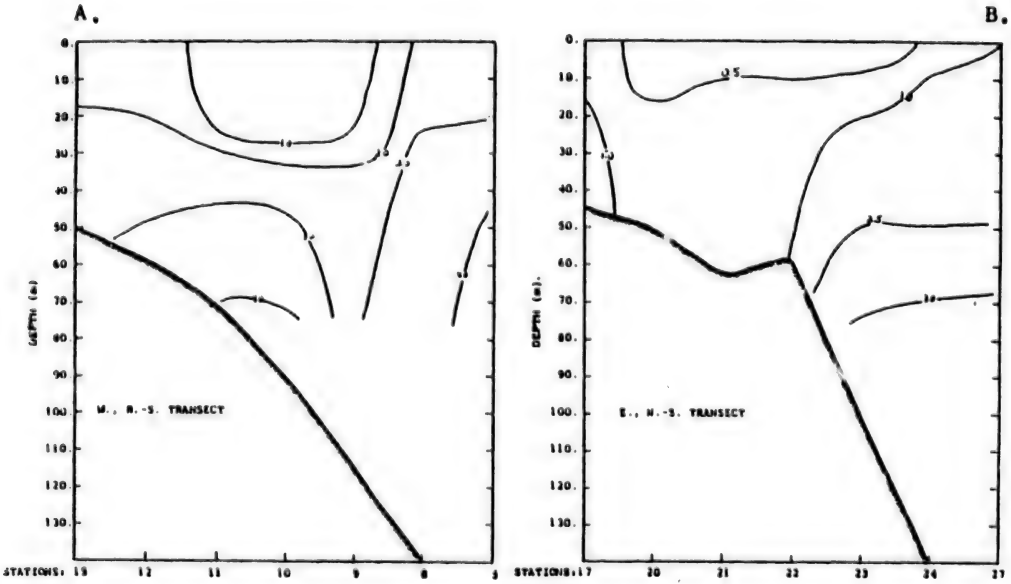

Figure 46. Phosphate isopleths from eastern and western transects.
a) Phosphate (as ug-at/l) isopleths from the western transect's first sampling.
b) Phosphate (as ug-at/l) isopleths from the eastern transect's first sampling.
North is to the left in the figure.

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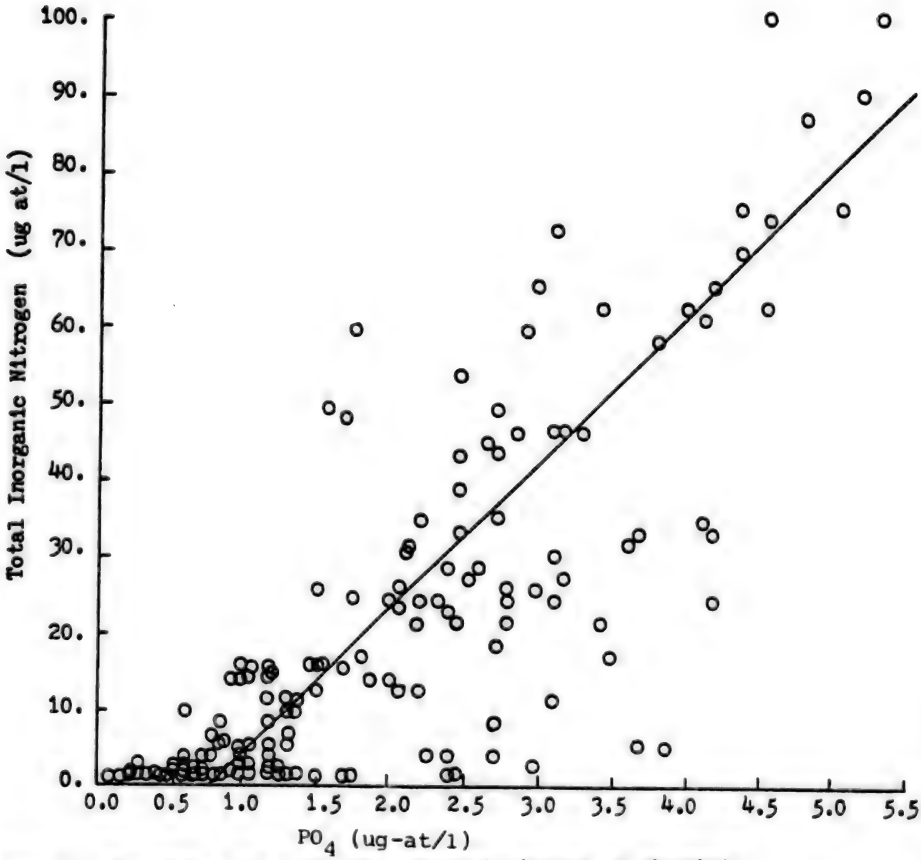

Figure 47. Geometric mean regression of total nitrogen on phosphate. Geometric mean regression of total inorganic nitrogen (as ug-at/l) on phosphate (as ug-at/l). Regression equation: $N = 18.86 \times PO_4 - 14.11$ ($r = .82$, 217 df, $p < .001$, 95% CL on slope : $\pm$ 1.43)

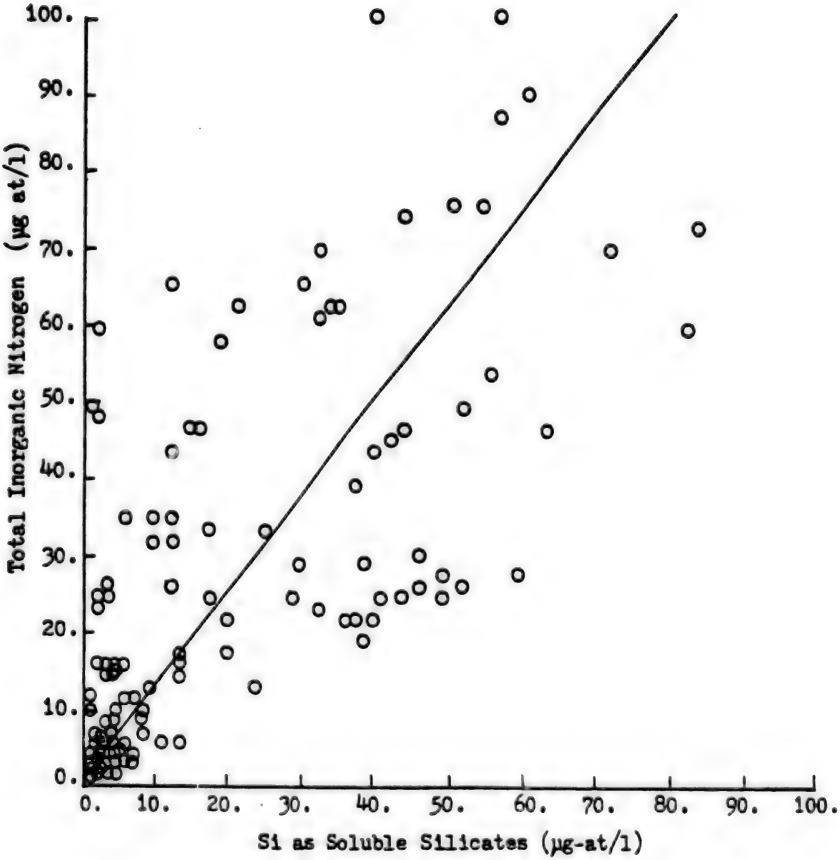

Figure 48. Geometric mean linear regression of total inorganic nitrogen (as ug-at/l) on Si (as ug-at/l) as soluble silicates.
Regression equation: $N = 1.27 \times Si + .96$
($r = .76$, 217 df, $p < .001$, 95% confidence limits on slope = $\pm$ .11)

on phosphate was performed to ellucidate a general stoichiometric decay ratio for phosphorous (as PO_4) and nitrogen (Fig. 47). The fitted slope with 95% confidence limits: 18.86 ± 1.43 ug-at N/ug at P is well within the range of values for N:P phytoplankton composition ratios reported by Ryther and Dunstan (1971) and Sakshaug and Holm-Hansen (1977). The intercept of the total nitrogen axis (-14.1 ug at/l N) indicates that nitrogen would be depleted prior to phosphate with continued decay at the given ratios.

The distribution of silica as soluble silicates closely resembles that of nitrate and phosphate. The strong vertical and horizontal gradients seen in vertical isopleths of silica from the first twenty-four stations (Figs. 49 and 50) indicate that the source of this nutrient, also is in the area of source water. Silica concentrations in the range of half saturation constants reported for many marine diatom species (Paasche 1973a, 1973b) were measured in the warm water above the thermocline at stations associated in coastal water and northern shelf water. Silica values were significantly correlated with inorganic nitrogen values ($r=.77$, 217 df, $p < .001$). A geometric mean linear regression of total inorganic nitrogen on silica (Fig. 48) yielded a slope of 1.27 ± .11 ug-at N/ug at Si.

Trace Elements in Seawater

Tables 14 and 15 show the concentrations of copper and lead in filtered Bering Sea water respectively.

The majority of the stations showed a slight increase in the copper content of the water column with depth. The average concentration of copper in the filtered Bering Sea water was 0.41 ug/l and the observed range was 0.08-1.02 ug/l. Figure 51 depicts the average concentration of copper in the upper 25 meters of the water column. Although the general trend in these data is an indication of increasing concentration of the metal with increasing station numbers it was observed that these changes were primarily related to local geography.

The lead content of the filtered sea water also showed a slight increase with depth at the majority of the stations. The average concentration of lead of the filtered sea water was 0.23 ug/l with an observed range of 0.03 - 0.68 ug/l. Figure 51 depicts the average concentration of lead in the upper 25 meters of the water column. As with copper the observed variations were related to local geography.

The results of analysis of sea water samples given in Table 16 are expressed in percentages, i.e. $\frac{\text{grams of metal} \cdot 100\%}{\text{grams of water}}$. At the first 24 stations the content of metals in the upper 50m was: mercury (0.5 to 5.84)$\cdot 10^{-8}$%; chromium (0.14 to 5.23)$\cdot 10^{-7}$%; zinc (0.5-15)$\cdot 10^{-6}$%; antimony (1.0-36.5)$\cdot 10^{-8}$%; silver (0.2-24.8)$\cdot 10^{-7}$%; bromine (0.34-13.7)%; gold (0.5-11.0)%. These data show that the content of microelements in sea water may vary by factors of 10 to 50.

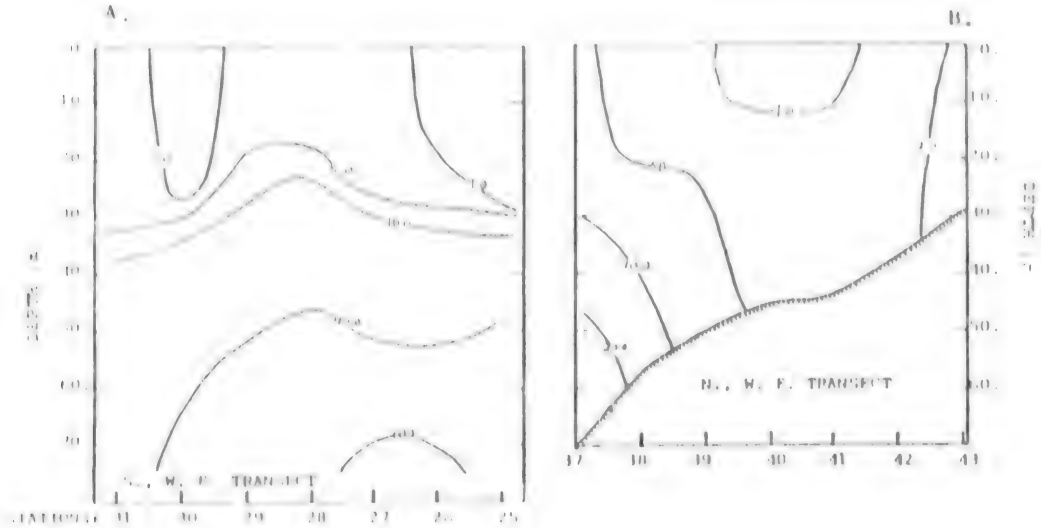

Figure 44. Silica isopleths from northern and southern transects.
A) Silica (as ug-at/l) isopleths from the southern transect's first sampling.
B) Silica (as ug-at/l) isopleths from the northern transect's first sampling.
West is to the left in the figure.

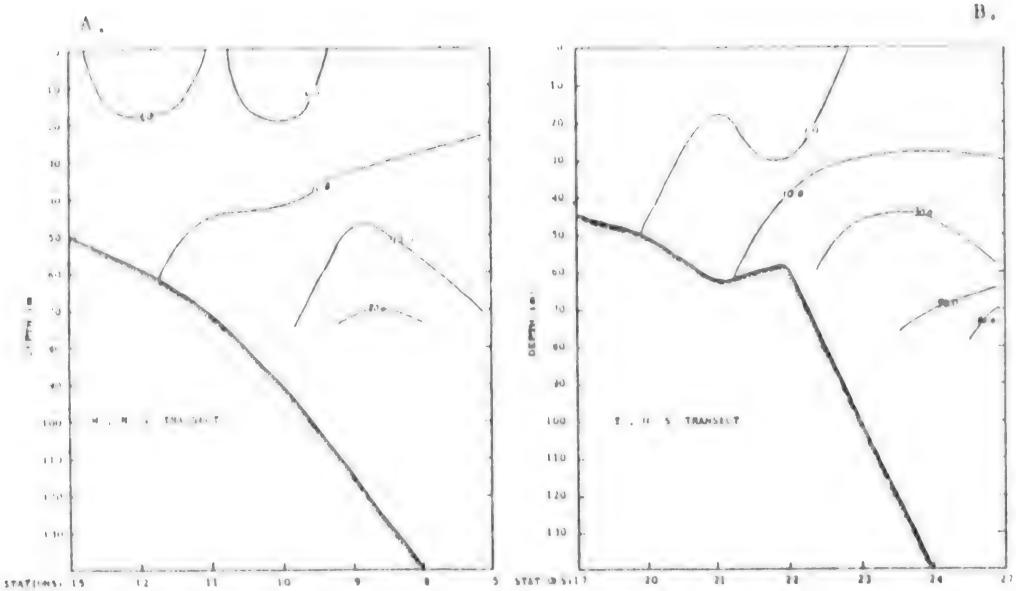

Figure 50. Silica isopleths from eastern and western transects.
a) Silica (as ug-at/l) isopleths from the western transect's first sampling.
b) Silica (as ug-at/l) isopleths from the eastern transect's first sampling.
North is to the left in the figure.

137.

138

Table 25

[illegible]

	1	3	5	7	9	11	13	15	17	19	21	23	25	28	30	32	34	36	38	40	42	44	46	48
[illegible]																								
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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35																					0.12			
40									0.83											0.84				
45								0.26														0.11		
50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.95				[illegible]	[illegible]
58											[illegible]													
65							[illegible]																	
75	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]						[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]							0.27

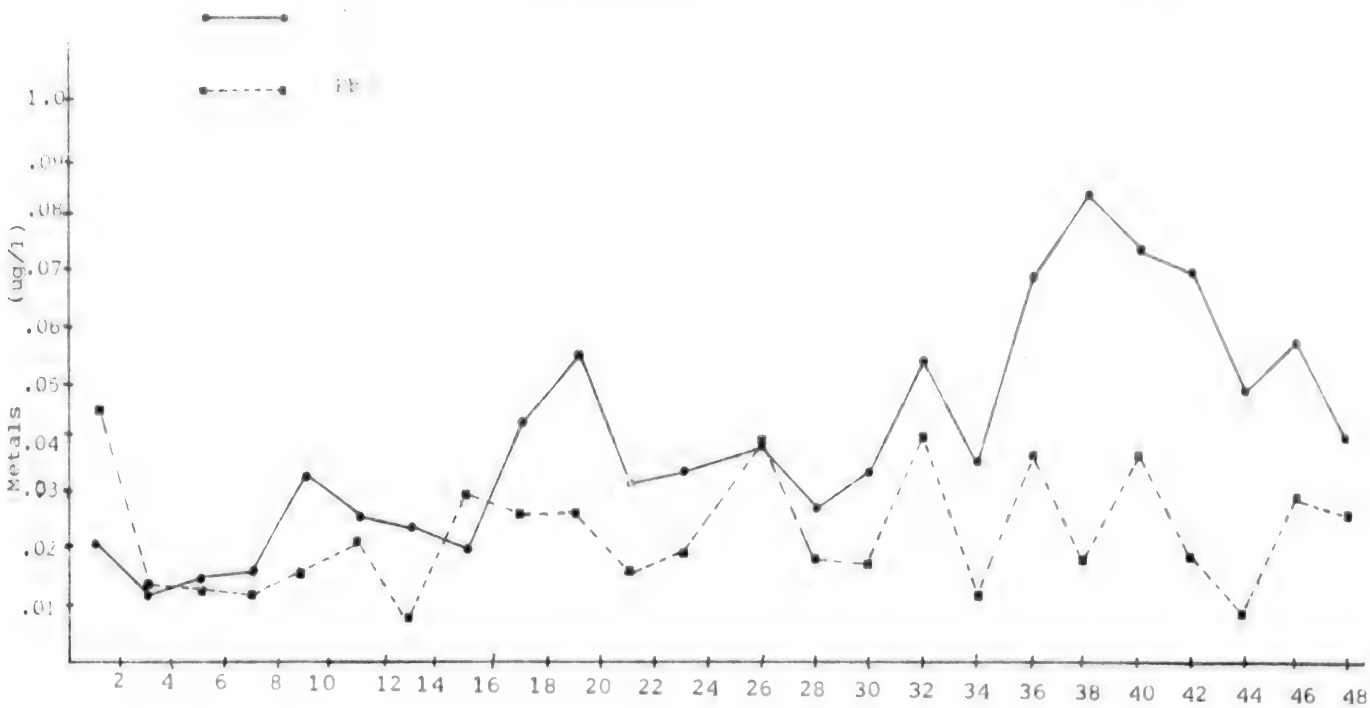

Figure 51. The average concentration (ug/l) of copper and lead in the upper 25 meters.

[illegible]

[illegible] of plankton present at each station is shown in Table 17. [illegible] of each of these samples is shown in Table 18. [illegible] of the surface plankton is shown in Table 19. [illegible] coefficients of these elements in the plankton is shown in Table 20.

[illegible] of microelements in plankton samples taken in the [illegible] varies as follows (Table 18): antimony (0.047 to 18.8)·10^{-7} [illegible]; [illegible] to [illegible]·10^{-6} g/g; zinc ([illegible]-[illegible])·10^{-5} g/g; [illegible]·10^{-8} g/g; mercury ([illegible])·10^{-6} g/g; iron ([illegible])·10^{-4} g/g; cobalt ([illegible]-11.4) g/g of plankton biomass.

The content of microelements in surface plankton (Table 19) is: mercury ([illegible] to [illegible])·10^{-5} g/g; iron (0.06 to 7.6)·10^{-3} g/g; chrome ([illegible]-141)·10^{-8} g/g; zinc ([illegible])·10^{-4} g/g; antimony (0.22-60)·10^{-7} g/g of plankton biomass.

Comparison of the data in Tables 18 and 19 shows that the content of microelements in surface plankton is approximately an order of magnitude greater than in plankton taken in the 0-50 m layer.

The coefficients of accumulation of microelements by plankton (Table 20) are: antimony (0.23 to 23.6)·10^{2}; chrome (0.1 to 12)·10^{3}; zinc ([illegible] to 22)·10^{3}; mercury (0.47 to 12)·10^{4}. As seen from these data mercury has the greatest capacity to accumulate in plankton. The coefficients of accumulation for specific microelements may vary by two orders of magnitude.

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.50	[illegible]	[illegible]
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[illegible]		1.82	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.45
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	[illegible]	[illegible]	[illegible]	[illegible]	13.4	1.11	[illegible]	[illegible]
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	[illegible]	[illegible]	.62	[illegible]	[illegible]	[illegible]	[illegible]	3.83
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	[illegible]	[illegible]	[illegible]	3.25	[illegible]	1.22	9.56	[illegible]
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	[illegible]	[illegible]	.22	[illegible]	[illegible]	1.56	7.27	1.35
	[illegible]	[illegible]	.79	4.64	[illegible]	[illegible]	11.4	3.62
[illegible]	[illegible]	.94	[illegible]	3.28	4.74	[illegible]	12.6	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.43
	[illegible]	[illegible]	[illegible]	5.67	[illegible]	[illegible]	7.56	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

*Concentration expressed as percentage, i.e.

[illegible]
[illegible] of [illegible] wet weight.

* Concentration expressed as percentages i.e.

$$\frac{\text{grams of metal} \times 100}{\text{grams of plankton wet weight}}$$

147

Table [illegible]

Concentration Coefficients of Elements in Plankton

Station No.	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	-
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	0.32
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	-
10	[illegible]	[illegible]	[illegible]	-
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 21

CONTENT OF ELEMENTS IN SURFACE PLANKTON,

[illegible] OF RAW WEIGHT

Station [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	-	-	-	-	[illegible]	[illegible]	0.11	[illegible]	[illegible]	[illegible]
[illegible]	-	-	-	-	[illegible]	[illegible]	0.11	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	33	[illegible]	1.45	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.43	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	-	-	-
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	43	[illegible]	-	-	-	-
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	44	[illegible]	1.38	15.67	6.17	6.47
21	0.34	43	8.14	5.48	45	[illegible]	0.55	13.1	1.13	6.47
22	2.34	[illegible]	3.15	4.00	46	[illegible]	-	3.7	3.30	4.56
23	0.75	[illegible]	2.80	8.07	47	0,47	0.061	0.78	0.25	0.96
24	0.34	[illegible]	2.12	6.24	48	[illegible]	0.15	2.13	3,70	0.22

Data on the content of the various metals in the blankets determined by the atomic absorption method are given in Table [illegible].

Low Molecular Weight Hydrocarbons

In the present area of study, there were different water regimes present in the sampling area. The first was an "open ocean" portion of the cruise track, the second a very shallow section (40 m) and the third was the transition zone between the aforementioned regions. Figures 52, 53, 54 show selected methane, temperature, and salinity profiles of these three zones.

The following stations comprise the area which is characteristic of "open ocean" conditions: 1-11; 23-35; 47; 48. The values for the depths are listed in Appendix 2, 3. They comprise the largest area and number of stations. The sampling depths are found in water which is sufficeintly removed from the sediment interface so as to be fairly representative of in situ water column production of hydrocarbons. The sampling depths did not extend to the bottom of the water column, and there is no way of determining whether the coldest waters at depth would exhibit light hydrocarbon concentration similar to the cold, shallow water environment.

Methane values in the "open ocean" section are supersaturated at almost all depths. Methane does not exhibit any subsurface

maxima as is generally found under other "open ocean" conditions. Ethane and propane also show no subsurface maxima and decrease in concentration with depth whereas methane remains fairly constant. The unsaturates, ethylene and propylene exhibit subsurface maxima at various stations. The butanes (iso and normal) are present only in trace amounts at all stations and are therefore not significant for discussion.

The second major grouping of stations (15-20, 39-44) comprises the shallow water environment. There is an extremely sharp thermocline at approximately ten meters. The saturated hydrocarbons (CH_4, C_2H_6, C_3H_8) are extremely high below the thermocline. Supersaturation for methane is as high as 300% at selected depths (usually bottom sample). The unsaturated hydrocarbons resemble the distribution found in the "open ocean" segment.

The intermediate zone (St. 17, 14, 21, 22, 36, 38, 45, 46) is a transition between the two aforementioned areas. As such, the vertical profiles of the hydrocarbons shift as one moves from the shallow water environment to "open ocean" conditions(Figs. 52, 53, 54). These stations were chosen based on the methane data and the thermocline depth and sharpness and are thus subject to some interpretive bias.

Carbon monoxide concentrations are extremely variable throughout the sampling areas. There is no set pattern to the

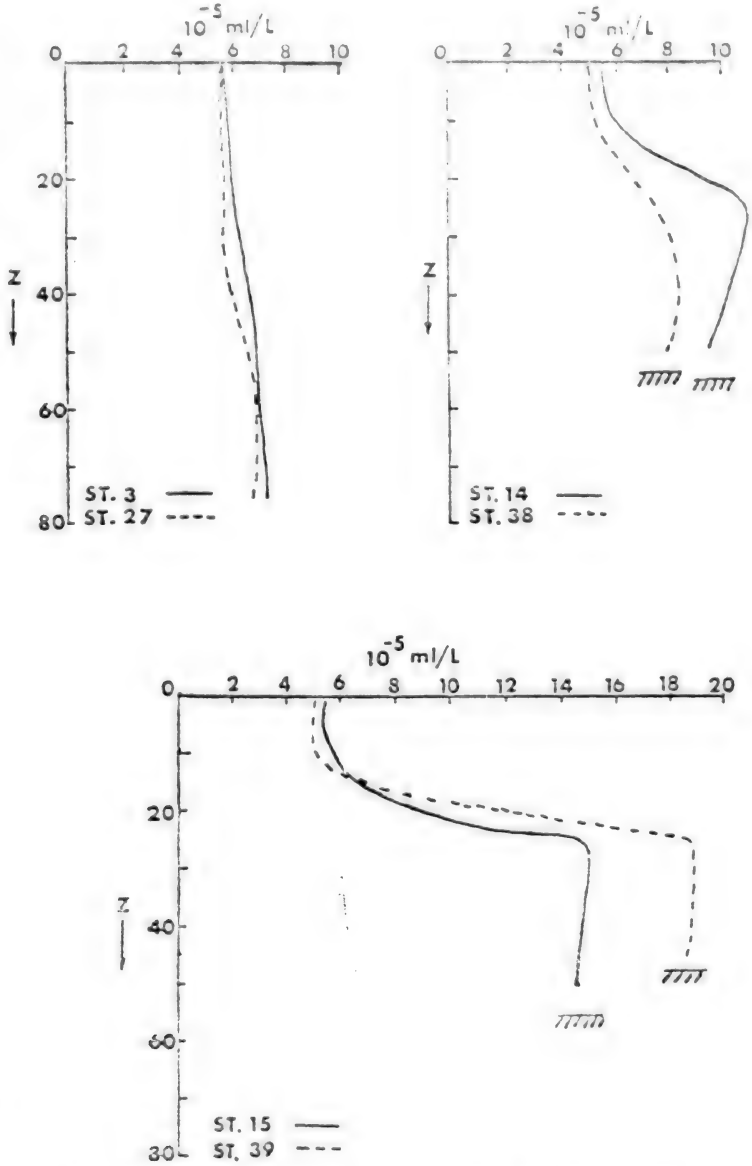

Figure 52. Vertical profiles of methane from the "open ocean" (st. 3, 27); intermediate zone (st. 14, 38), and shallow water (st. 15, 39). Concentrations are expressed as 10^{-5} ml/l. The two plots represent the two stations taken at the same coordinates.

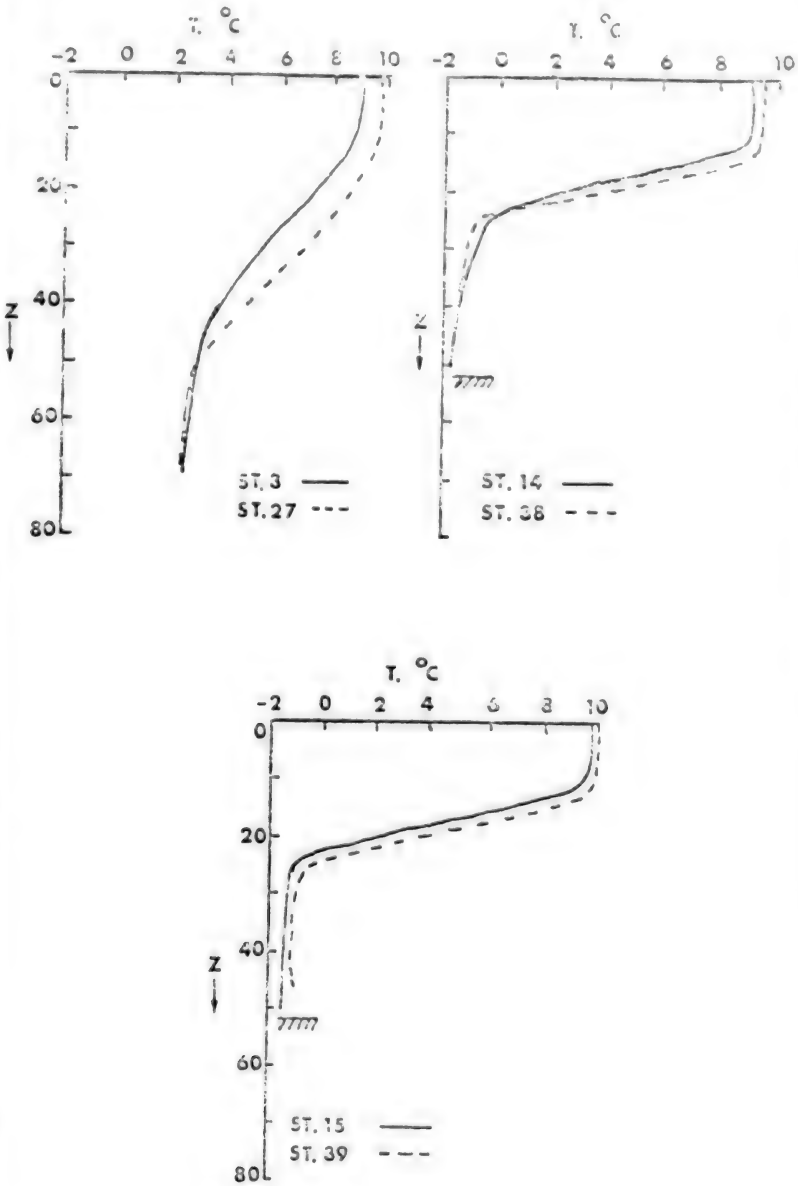

Figure 53. Vertical profiles of temperature with the same conditions as Figure 52.

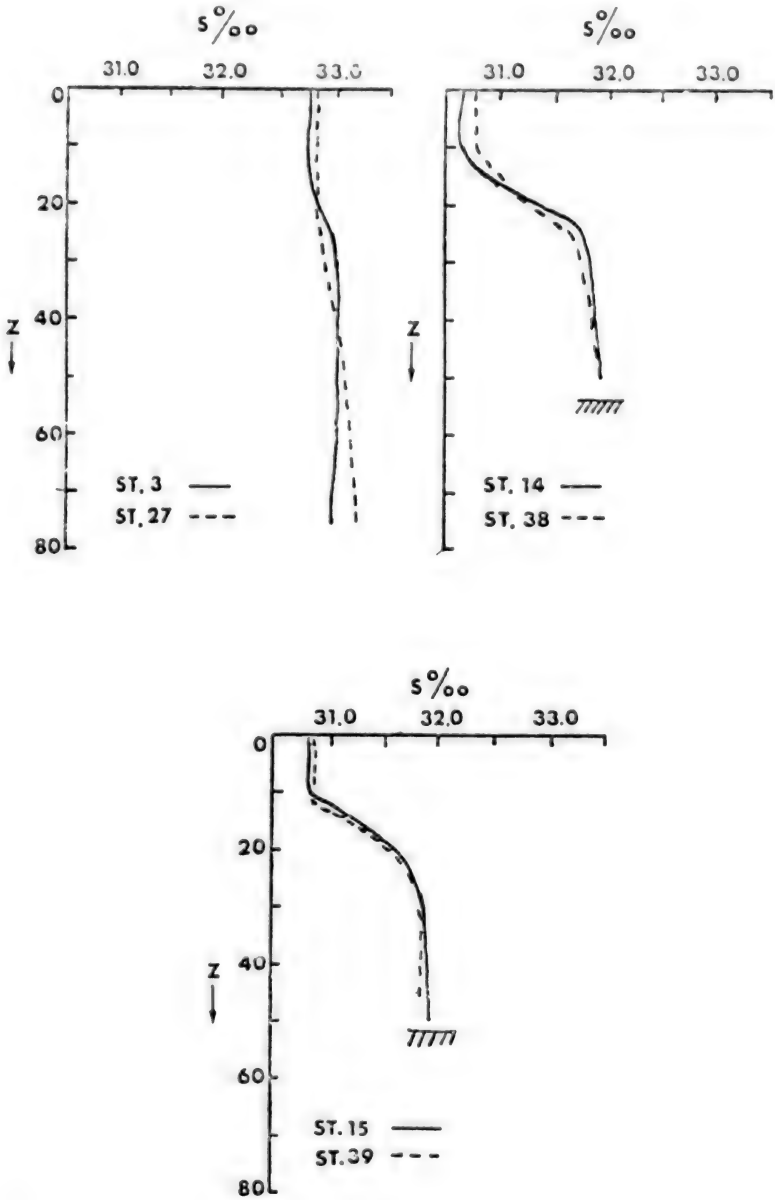

Figure 54. Vertical profiles of salinity with the same conditions as Figure 52.

carbon monoxide distribution with the available auxillary data. The randomness will be considered further in the discussion.

Results of the analysis of the heavier hydrocarbon fraction in the surface microlayer and the depths of 0 and 50 m are given in Figure 55. In the same figure a curve of the distribution of the biomass of plankton in the layer 50 to 0 m is also given. Comparison of this curve with the distribution of hydrocarbons in the water (curves 2 and 3) shows that the accumulation of biomass of plankton in the water in the second stage (stations 24 to 48) led to an increase in hydrocarbon content. In contrast, the content of hydrocarbons in the surface microlayer practically did not increase, i.e., the change in the content of biomass in the water did not have a significant effect on the concentration of hydrocarbons in the surface microlayer.

The average values of total hydrocarbons for the first 25 stations were: surface microlayer, 0.345 mg/liter; at depth 0 meters, 46 ug/liter; at a depth 50 meters, 44 ug/liter. In the second stage (stations 25 to 48) the average values for the /total/ hydrocarbons were as follows: surface microlayer, 0.355 mg/liter; at depth 0 meters, 110 ug/liter; and at depth 50 m, 85 ug/liter. In the second stage in comparison to the first, the concentration of hydrocarbons increased at the 0 meters depth by 2.4 times, and at the 50 m depth by 1.9 times.

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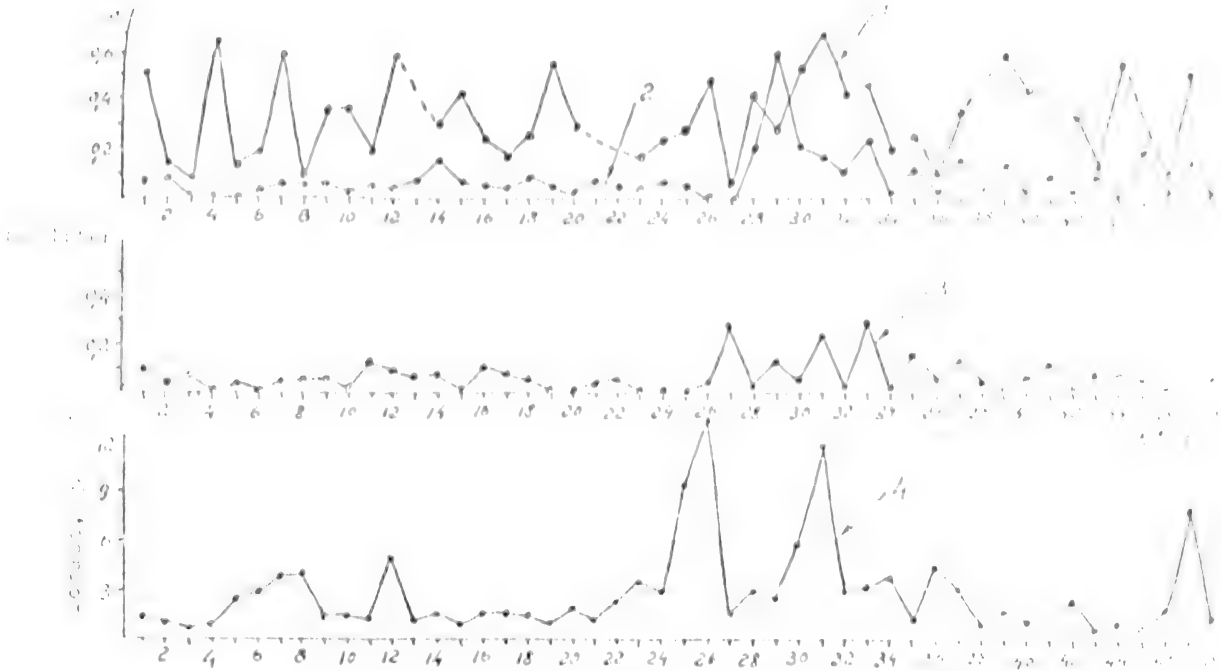

Figure 55. Content of hydrocarbons in plankton in the water.
Curve 1 - concentration of hydrocarbons in surface microlayer.
2 - concentration of hydrocarbons at the 0 m depth.
3 - Same, at 50 m.
4 - Concentration of plankton in layer 0 to 50 m.

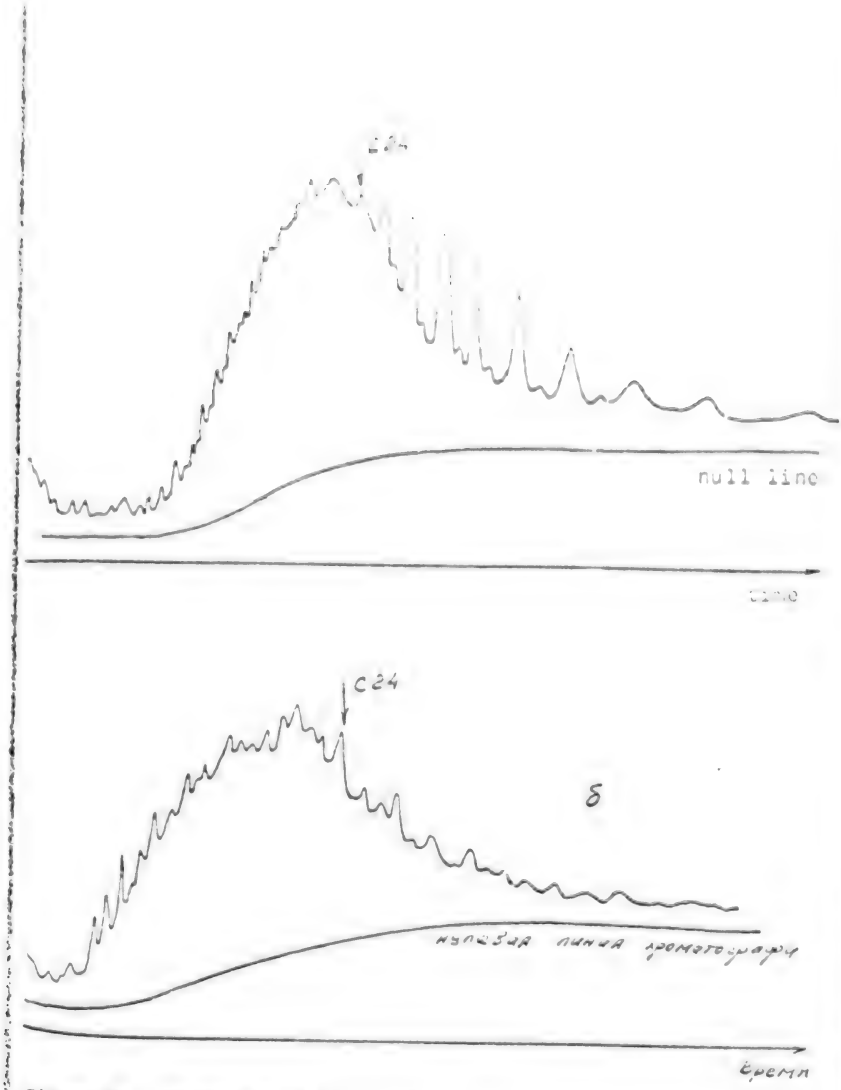

Figure 56. Chromatograms of water samples
a) surface microlayer
b) sample of water from depth 0 m

In Fig. 56 characteristic chromatograms of the water samples are shown. The chromatogram of the surface microlayer is characterized by the presence of a "hump" with a maximum in the region of the C_{22} to C_{24} hydrocarbons. In the region above C_{24}, significant peaks of normal paraffins are observed. The maximum of the "hump" in the chromatogram of the water sample from the 0 meters depth is also located in the region C_{20} to C_{24}, but the relative content of heavy hydrocarbons in this sample was much less than in the sample from the surface microlayer. In the sample from the surface a high content of light hydrocarbons, in the region below C_{20} was observed.

The results of the measurements of benzo(a)pyrene (BP) in water are shown in Table 22.

Determinations of BP were also carried out on several plankton samples. The concentration of BP in the plankton sampled from stations 13, 17, 30, 33, and 44 were, respectively, 0.439, 0.842, 0.671, 0.755, and 0.403 mg/kg of dry weight of plankton. The average value was 0.622 mg.kg of dry weight.

Table 22

Concentration of benzo(a)pyrene
in water, ug/liter

Station No	Surface Microlayer	0 m	10 m	25 m
8	- *	0.005	-	-
10	0.075	0.019	0.015	0.011
12	0.077	0.007	0.017	0.014
14	0 149	-	-	-
15	-	0.016	-	-
16	-	0.034	-	-
18	-	0.007	-	-
20	-	0.015	0.002	0.008
22	-	0.010	0.008	-
25	-	0.020	-	-
26	-	0 024	-	-
27	-	0.008	-	-
28	-	0.022	-	-
29	-	0.011	-	-
30	0.087	0.025	-	-
31	0.213	0.008	-	-
32	-	0.015	-	-
46	0.198	-	-	-
Ave. value	0.125	0.014		0.011[a]

[a] (Concentration values for the 10 m and 25 m levels are combined.)

* Samples were not taken where dash appears.

Figure 57. Distribution of depth average chlorophyll a
Chlorophyll a (as mg/m^3) iscpleths from data
of stations I-24.

[illegible]

[illegible]

The [illegible] *a* [illegible] exhibit the striking horizontal gradient observed for nutrients. The depth averaged concentration of chlorophyll *a* for stations 1-[illegible] were employed in developing the isopleths in Figure [illegible]. The range of observed chlorophyll *a* values over the entire sampling area for both samplings was [illegible] mg chl *a*/m^3.

The results of phytoplankton analysis showed that diatoms *Coscinodiscus oculus iridis*, *C. exentricus*, *Chaetoceros concavicornis*, *Ch. convolutus*, *Rhizosolenia hebetata* and *Thalassiosira* sp. were dominent along with two species of dinoflagellates: *Ceratium tripos* and *C. lineatum*. A substantial increase in chlorophyll between reoccupation of stations near the continental shelf appears to reflect a bloom of *Rhizosolenia hebetata*.

The highest chlorophyll *a* concentrations were associated with the pycnocline at the more severely stratified stations. In general, the appearance of subsurface chlorophyll *a* maxima was related to the severity of the pycnocline. An illustration of this phenomenon can be seen in a plot of sigma-t values and chlorophyll profiles for stations 31, 32, and 38 in Figure 58.

The slope of a linear approximation of the pycnocline's chlorophyll *a* concentrations at each station was used as a finite estimate of stability in the pycnocline. Stability was then related

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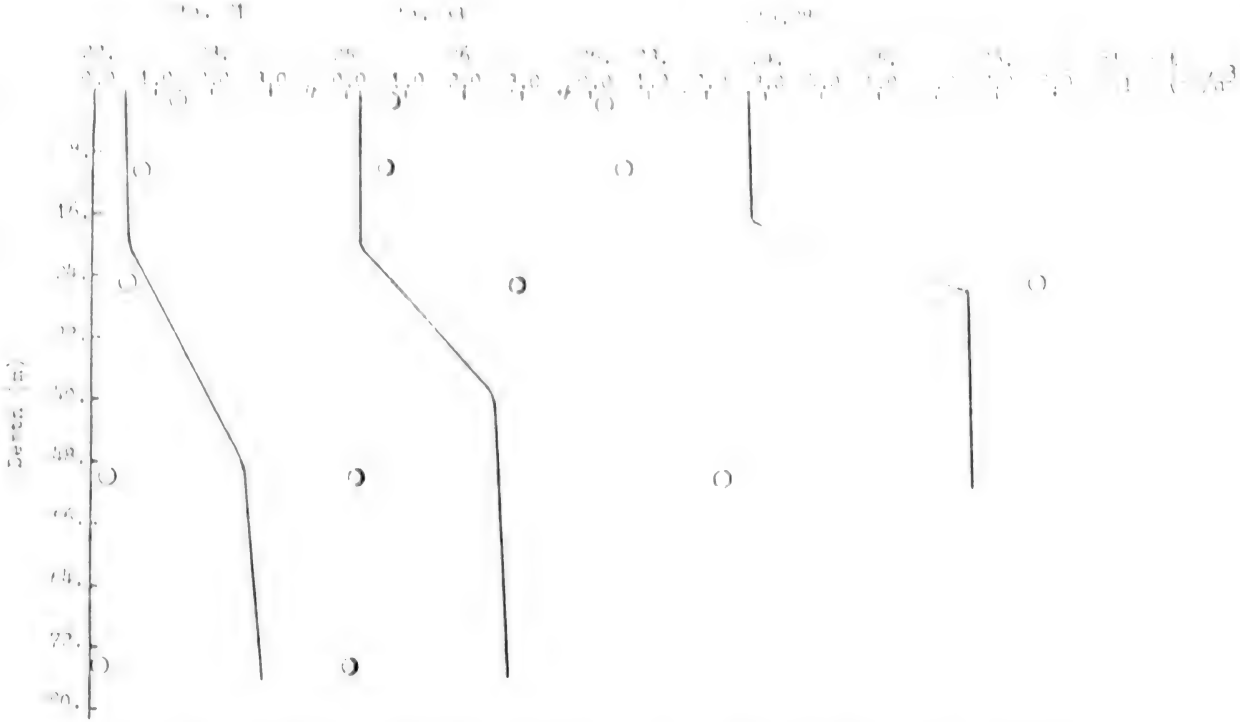

Figure 58. Density stratification and chlorophyll a vertical distribution relationship. Density as sigma-t is presented for three stations in solid lines. Chlorophyll a (as mg/m^3) is presented for stations 31 and 38 as open circles and for station 33 as closed circles.

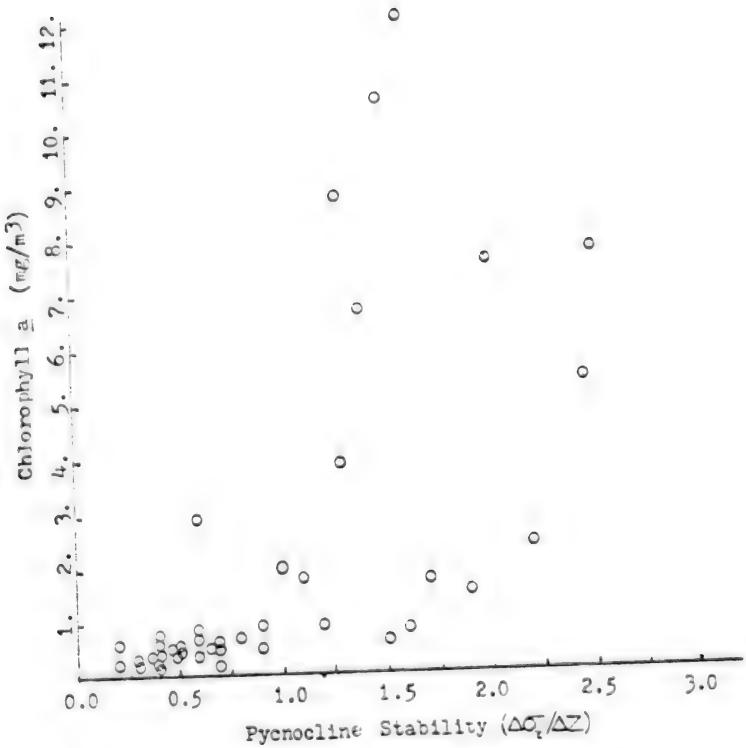

Figure 59. Pycnocline stability and pycnocline associated chlorophyll concentration relationship. Pycnocline stability expressed as $\frac{\Delta\sigma t}{\Delta Z}$ plotted against chlorophyll a concentration (as mg/m^3).

to the pycnocline [illegible] concentration in Figure [illegible] the non-linear pattern observed in this figure is consistent with that would be expected based upon the Stokes' [illegible] equation for the sinking rate of a body in a liquid medium:

$$V = \frac{g}{\eta} r$$

where v - the velocity of the body

g - the acceleration of gravity

r - the radius of the body

η - the viscosity of the liquid

p and ρ - the density of the body and the liquid, respectively.

The density difference in the thermocline was primarily the effect of temperature which also affects the relative viscosity of the fluid (Dietrich [illegible]). Thus, the velocity would be slowed in a nonlinear manner with increasing thermocline stability due to the effect of both decreasing density difference and increasing viscosity.

Stepwise multiple regression analysis with chlorophyll a concentrations as the dependent variable and nutrient concentrations as the independent variable yielded no significant relationships ($p > 0.05$) between their distributions.

a. Temporal Variation in Chlorophyll a and Nutrient

Chlorophyll a and nutrient [illegible]

Table 23

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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a depth of 25 meters using trapezoidal integration and changes in their concentrations at each station over the time interval between samplings were examined (Table 23). Relatively large decays of nitrogen, silica and phosphorous concentrations were associated with increases in chlorophyll along the southern transect at the continental slope. The most dramatic changes were observed at station 2, located at the time of the Zhemchug Canyon. The stations at the northern end of the study area exhibited a general decrease in chlorophyll a concentration over the sampling interval. Ammonia production was evidenced at stations where substantial decreases in chlorophyll a were noted. Regression analysis was performed with nutrient and chlorophyll a data from the subset (Table 23) associated with positive changes in chlorophyll a concentration to determine the relative importance of inorganic nitrogen, silica and phosphorous on the observed increase in chlorophyll a. This segregation of the data set is legitimate if one considers the effect of differential food chain passage of chlorophyll a and nutrients on regressions where a decrease in chlorophyll a was observed. It is assumed that predation could be occurring while chlorophyll a concentrations increase.

Stepwise multiple regression was performed with the finite rate of increase in chlorophyll a as chl a/ t in Table 23 as the dependent variable and the rates of change of silica, phosphorous and total inorganic nitrogen as independent variables. Silica was

the most important of the independent variables tested reducing 6.7 of the variance in the distribution of the rate of change of chlorophyll a concentration. Analysis of variance indicated a significant relationship ($p <$). [illegible] between these two variables. Inorganic nitrogen was second in importance and although not significantly related to chlorophyll a individually, when combined with silica in the analysis reduced 24% of the variance in the chlorophyll a growth rate. Phosphate decay accounted for only an additional [illegible]% of the variance in chlorophyll a growth rate in the analysis and was not significantly related individually to the rate of chlorophyll a increase.

2) Phytoplankton and Zooplankton

a) Distribution of Dominant Species of Phytoplankters.

The predominant phytoplanktons of this region were diatoms (Coscinodiscus oculus iridis, C. excentricus, Chaetoceros concavicornia, Ch. convolutus, Rhizosolenia hebetata, and Thalassiosira sp.) and peridiniaceous algae (Ceratium tripos and C. lineatus). The distribution over the study area of the dominant species of algae and their relative abundance are shown in Fig. 6C.

The most frequently encountered species at the edge of the shelf were C. tripos, Rh. hebetata, C. excentricus, and C. oculus iridis, and in the shallow part of the shelf C. oculus iridis, C. tripos, and Th. sp. (Table 24).

The population distributions over the study area and with depth, of the most abundant species, C. oculis iridis, are shown

in Fig. 60. As is seen, in the shallow part of the region the population of this species was significantly higher than at the edge of the shelf.

The predominant mass of algae was found deeper than the layer of temperature discontinuity in waters with low salinity and relatively high nitrite content (Fig. 66 and Fig. 68). The population distribution of Coscinodiscus among stations and with depth in the first and second stages of sampling was practically the same. In the deep water section of the sampling polygon, C. oculis iridis was regularly encountered, but its population was fairly low and substantially lower than in the shallows.

It is characteristic that the distribution of Thalassiosira sp. in the shallowest part of the polygon was confined to those areas of the water which were characterized by low salinity and low temperature (stations 14, 15 and 16 in the first stage, and station 37, 38, and 39 in the second stage). At other stations of the polygon this species was not found.

b) Distribution of Dominant Species of Zooplankters.

Among the zooplankton the most populous forms were the copepods: Oithona similis, Pseudocelanus elongatus, Calanus plumchrus, Acartia longiremia, Eucalanus bungii, and Metridia pacifica: and the Chaetognathum, Sagitta elegans. In addition, Calanus cristatus, Oncaea borealis, and Thysanoessa longipes,

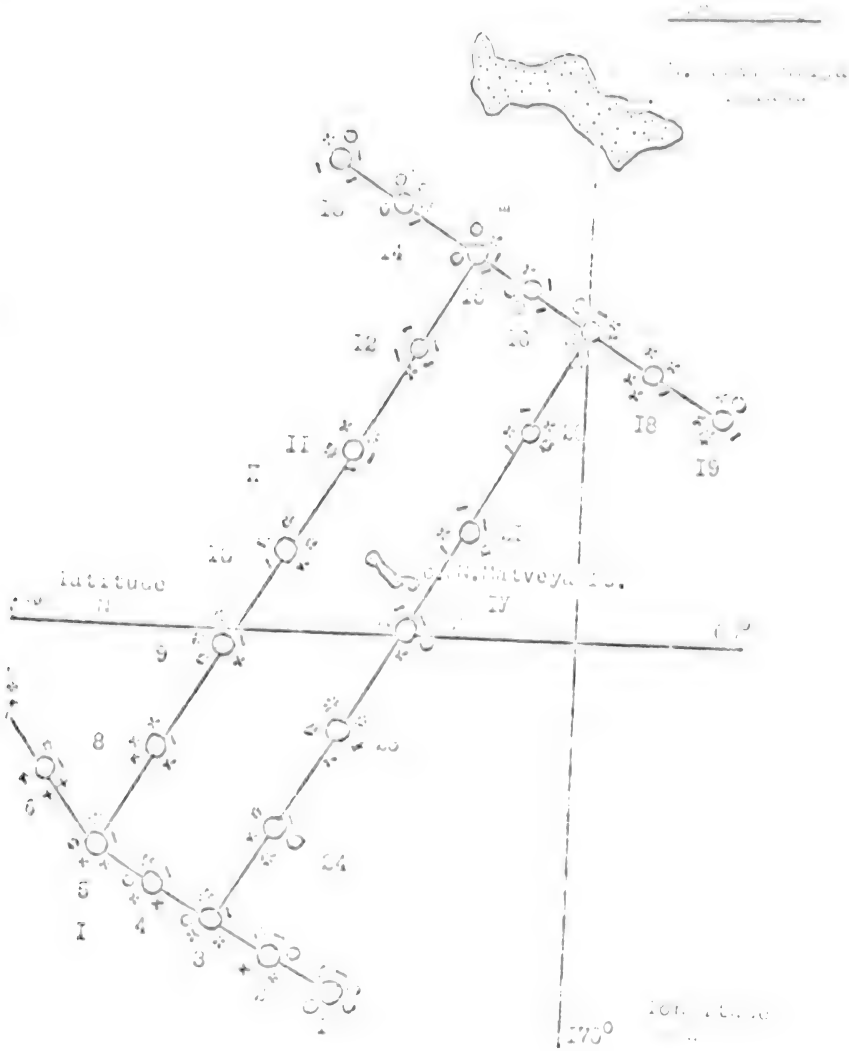

Figure 60. Spatial distribution and relative abundance of dominant forms of phytoplankters on the polygon in the Bering Sea-Stare 1

— Coscinodiscus
o Thalassiosira
✚ Chaetoceros
× Ceratium
O Rhizosolenia

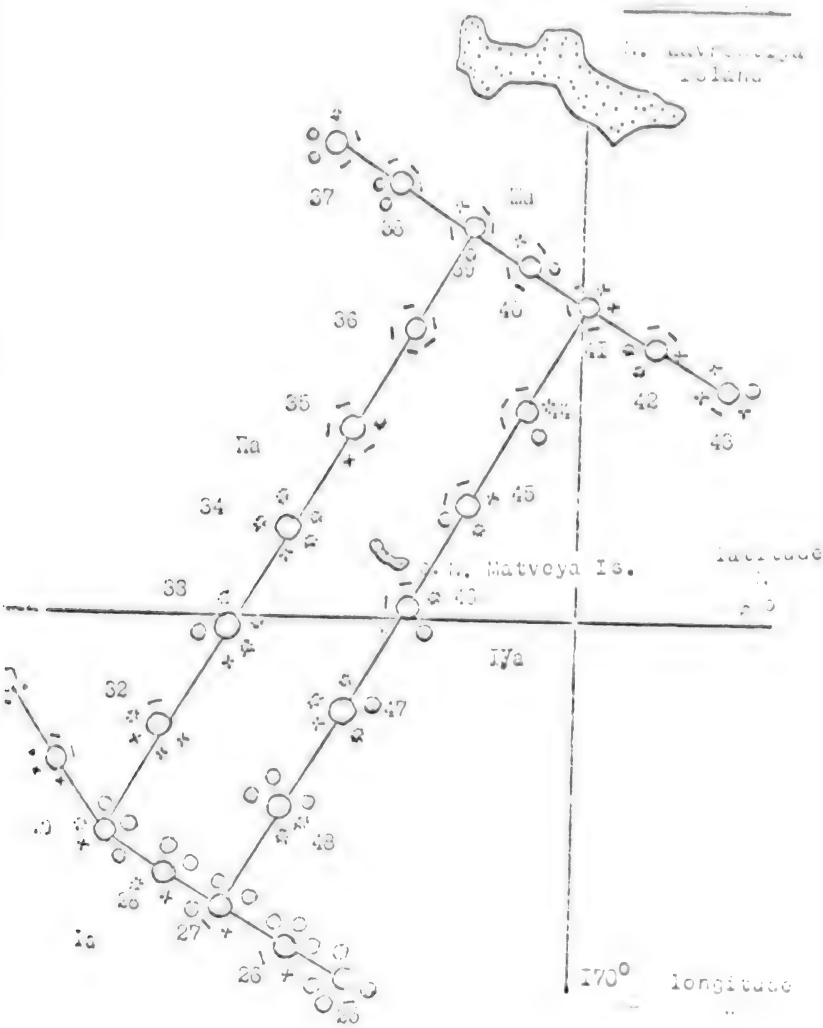

Figure 61. Spatial distribution and relative abundance of dominant forms of phytoplankters on the polygon in the Bering Sea - Stage 2.

— Coscinodiscus
o Thalassiosira
✱ Chaetoceros
× Ceratium
O Rhisosolenia

Table 21

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	-	-	14	-	65	-
[illegible]	[illegible]	[illegible]	[illegible]	-	-	42	42	-
[illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]	-	56	22
[illegible]	[illegible]	[illegible]	-	-	-	50	83	-

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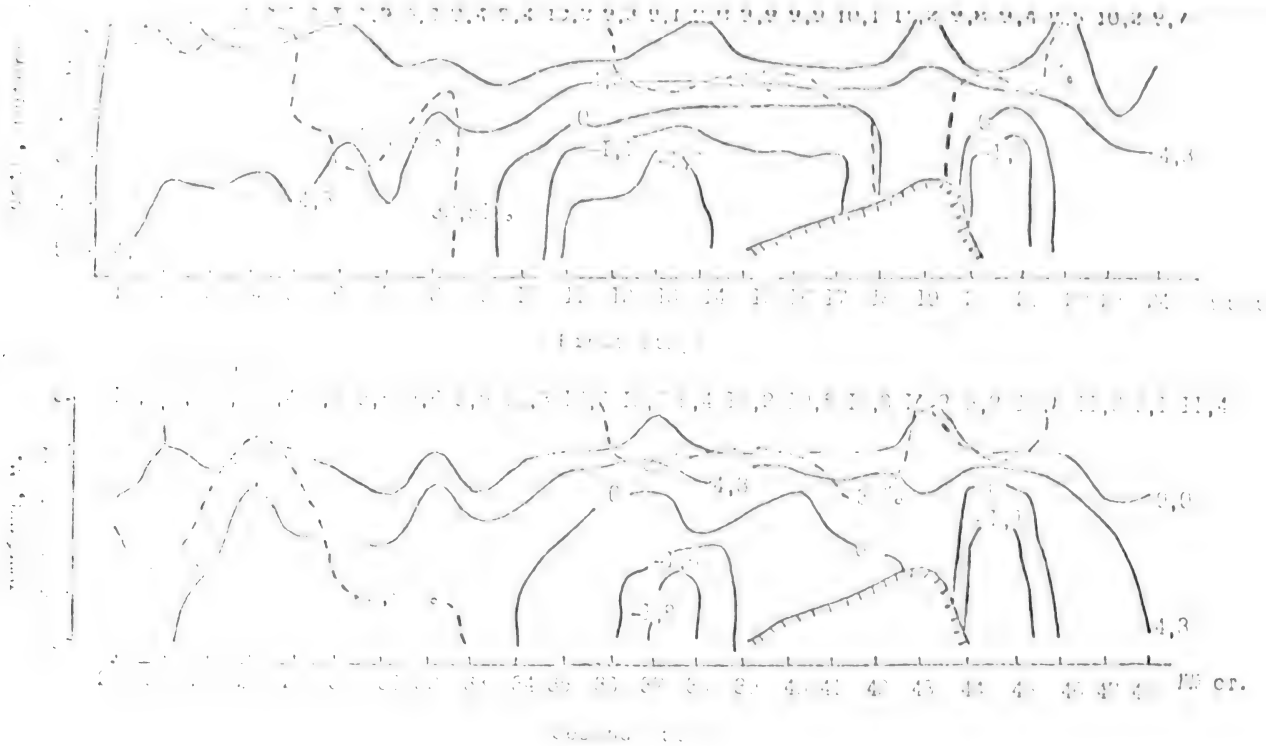


Figure [illegible]. Spatial distributions of temperature and salinity on the study polygon in the Bering Sea.

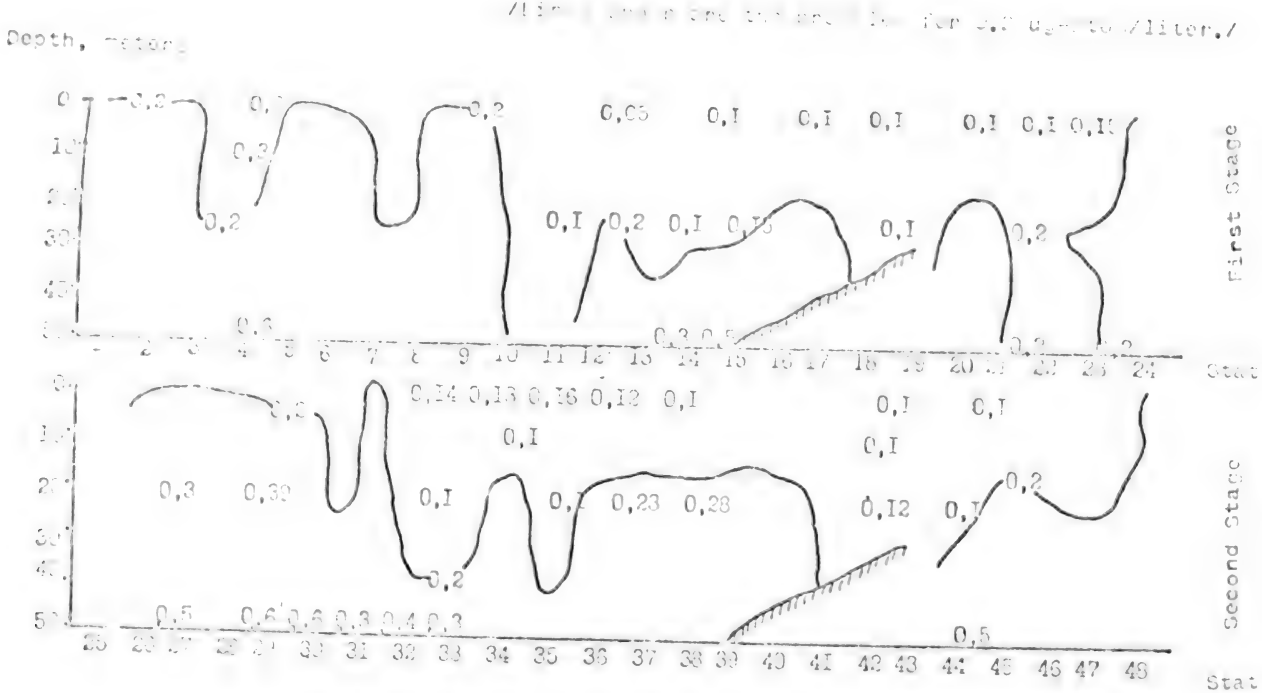


Figure 63. Spatial distribution of nitrites, in microgramatoms per liter, on the study polygon in the Bering Sea.

Table 25

[illegible]

[illegible] (Transects III and IIIa) [illegible]

[illegible] (Tr[illegible])

		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	I	[illegible]	[illegible]	[illegible]	100	130	270	89	29
	II	-	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	-
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	570	-	2
	[illegible]	-	[illegible]	[illegible]	130	90	[illegible]	[illegible]	-

[illegible]

174

larva of benthic invertebrates (echinoderms, polychaetes, bivalves and gastropod molluscs), and the cladoceran, Evadne nordmanni were found.

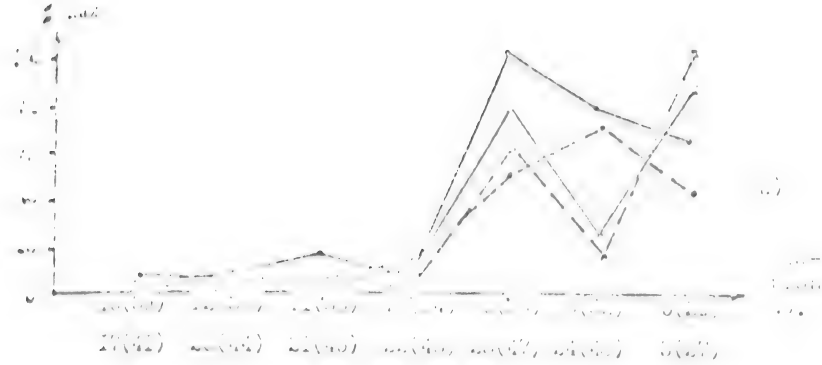
Differences in the species composition and in the populations of the different species of zooplankton between deep water (transects I and Ia) and shallower water (transects III and IIIa) areas of the polygon are noteworthy. Thus, C. cirstatus, E. bungii, O. vorealis, and Th. longipes were found only on the edge of the shelf in transects I and Ia. At the same time, meroplankton and E. nordmanni were mainly encountered in the shallows. Transects I (Ia) and III (IIIa) also sharply differed in the average population of dominant species of zooplanktons (Table 25). At the edge of the shelf a very high population of O. similis was found; the populations of A. longiremis and P. elongatus turned out to be sharply higher in the interior of the shelf.

The variation in the population (expressed as percent of the maximum value for all samples) of the dominant species along the transects which were perpendicular to the edge of the shelf (transects II and IIa, and IV and IVa) is shown in Fig. 64. The typical oceanic species E. bungii was found in the greatest amount in the region of the depth, while over the shelf its population was much lower. This species was not encountered in the shallow region of the polygon. The cosmopolitan species O.

similis also had high population at the edge of the shelf. In the littoral part of the polygon, cithoma were regularly found, but in low populations. An example of a species which was more populous in the interior of the shelf is A. longiremis (Fig. 65). P. elongatus, S. elegans, and C. plumchrus (Fig. 66) were found at nearly all stations of the polygon. The maximum populations of these forms were found at various locations. P. elongatus and S. elegans had high populations both at the deepest and at the shallowest parts of the study area.

It is important to note that the sampling of the polygon in two time frames allowed conclusions to be made about changes over time in the phyto- and zooccenoses which took place over a period of seven days. In this interval of time the composition of dominating species of phytoplanktons did not change significantly in the interior of the shelf (compare transects III and IIIa in Table 26); during the second stage of the study (transect Ia) Rh. hebetata, C. oculus iridis, and Ch. convolutus were encountered on the edge of the shelf in addition to C. tripos. Thus, in the deep-water section of the polygon over the period between the first and second sampling periods, substantial changes took place in the phytocoenosis, while in the shallow part of the polygon the changes were insignificant.

The biomass of plankton meeted in the layer 0 to 50 m (fig. 67) did not change significantly over the 7 days in the shallows. However, in the deeper region (transects I and Ia) the biomass of zooplankton increased significantly, due primarily to large-sized zooplankters.



[illegible] (Distribution [illegible] of the maximum) [illegible] O. [illegible] and (b) [illegible], along the [illegible] perpendicular to the edge of the shelf.

Transect II Transect IV
Transect IIa Transect IVa

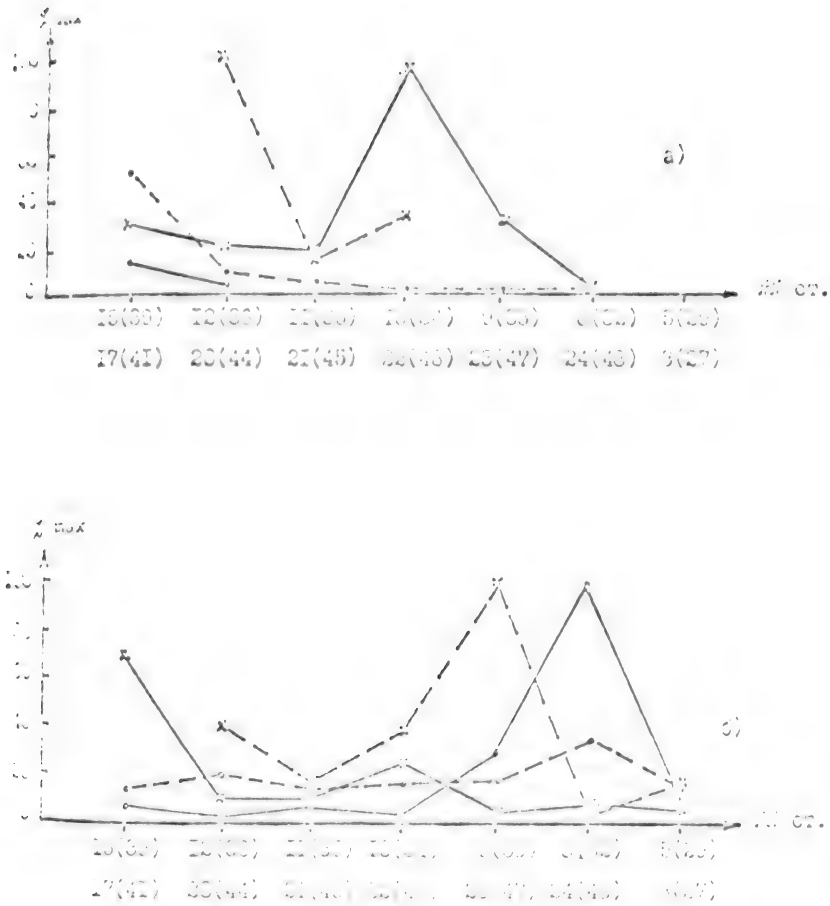


Figure 19. Population distribution (in % of the maximum) of (a) A. longiremis and (b) P. elongatus, along the transects of perpendicular to the edge of the shelf. (Line codes, etc. are as in Fig. 18 above)

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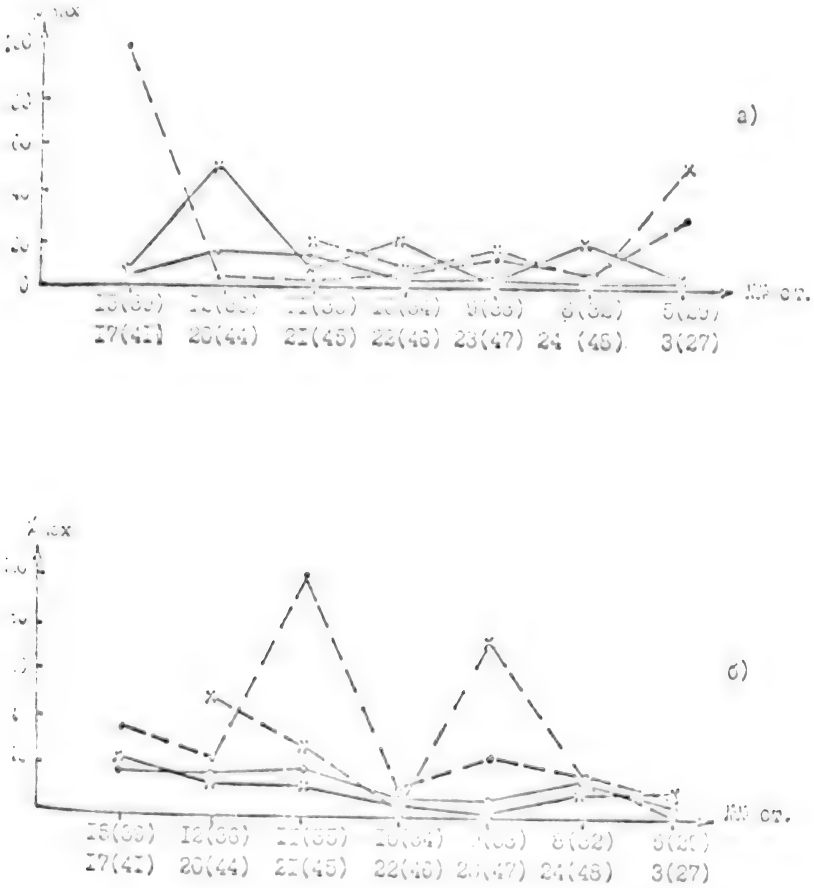

Figure 66. Population distributions (in % of maximum) of (a) S. elegans and (b) C. plumchrus, along the transects perpendicular to the edge of the shelf. (Codes and labes are as in Fig. 60above).

Table 26

Dominant Species of Phytoplankters near the Edge (Transects I and Ia) and in the Interior (Transects III and IIIa) of the Shelf, in the First and Second Stages of the Study

Transect No.	1st Stage (30.7.-5.8.'77r.) Station No.	Transect No.	2nd Stage (6.8.-12.8.'77r.) Station No.
I	1 Coscinodiscus excentricus Rhisosolenia hebetata	Ia	25 Coscinodiscus excentricus Rhisosolenia hebetata
	2 Ceratium tripos		26 C. excentricus C. oculus iridis Rh. hebetata
	3 C. tripos		27 C. tripos Rh. hebetata
	4 C. tripos		28 C. tripos Chaetoceros convolutus
	5 C. tripos		29 C. tripos C. lineatum Ch. convolutus Rh. hebetata
	6 C. tripos		30 C. tripos C. lineatum C. oculus iridis
	7 C. tripos		31 Ceratium sp. C. oculus iridis
	13 C. oculus iridis Chaetoceros concavicornis		37 C. oculus iridis C. tripos Thalassiosira sp.

III	1[illegible] Thalassiosira sp.	IIIa	[illegible] Th. sp.
			C. oculus iridis
	1[illegible] Thalassiosira sp.		[illegible] Th. sp.
	C. oculus iridis		C. oculus iridis
			C. tripos
	[illegible] Th. sp.		[illegible] C. oculus iridis
	C. oculus iridis		C. tripos
	C. tripos		
	1[illegible] C. oculus iridis		[illegible] ____ " ____
	C. tripos		
	1[illegible] C. oculus iridis		[illegible] C. oculus iridis
	C. tripos		C. tripos
	1[illegible] Coscinodiscus sp.		[illegible] Chaetoceros sp.
			C. excentricus
			C. tripos

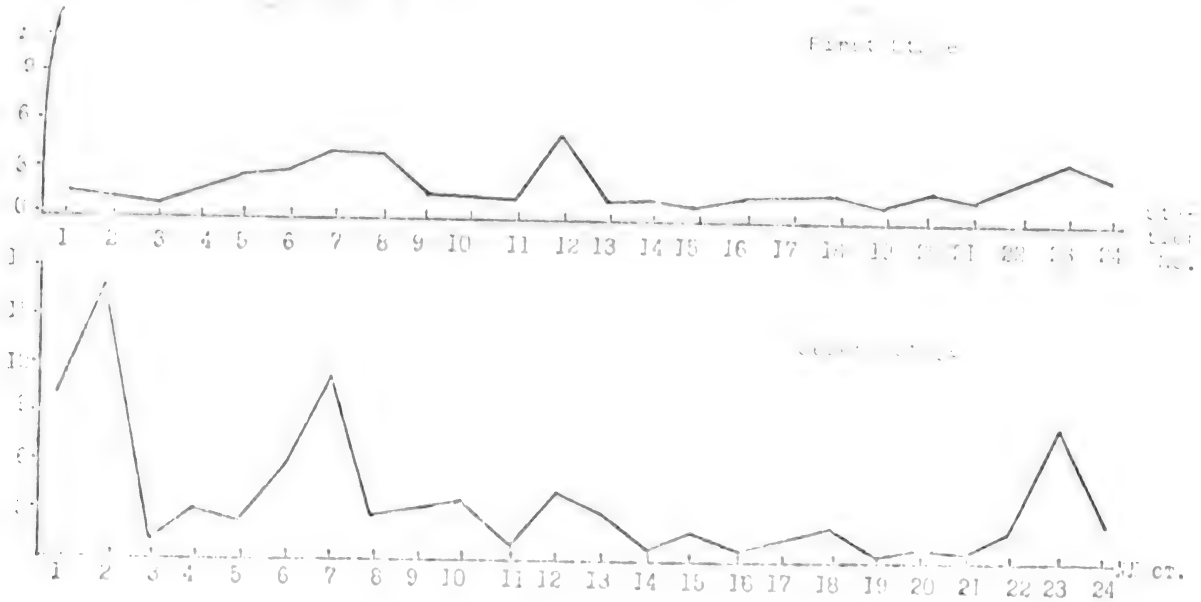

Figure 67. Distribution of biomass of plankton along the transects in the study polygon in the Bering Sea.

Even more marked differences between shallow-water and deep-water parts of the polygon were found in the distribution of zooplankters. Oceanic forms such as C. cristatus, E. bungii, and Th. longipes occurred only in region near the edge of the shelf; the typically neritic organisms -- the larvae of benthic invertebrates and E. nordmanni -- were encountered only in the shallows. The largest variety of neritic forms of zooplankters were encountered near the islands of North Lavrentiya and North Matveya. Among the most dominant species some had their high populations at the edge of the shelf (C. similis), and others, e.g. - in the shallows. The population of dominant species of zooplankters was markedly higher at the edge of the shelf (9500 organisms per cubic meter) than in the depths (2500 organisms per cubic meter).

The results obtained indicate the existence of two distinct communities -- neritic and oceanic -- of inhabitants in the area of the Bering Sea which was examined. In the greater part of the polygon a neritic community was observed, and characteristic features of an oceanic community were observed in the deeper region.

A. K. Heinrich (1962), exploring the basic planktonic communities of the Pacific Ocean, indicated that in the community of the oceanic zone of the Bering Sea the biomass of the zooplankton per unit of area was large while the biomass of phytoplankton was small. Large-sized, herbivorous copepods dominated (Calanus cristatus, C. plumchrus, and E. bungii). In the community of the

[illegible]

[illegible] Fyomina [illegible] noted the confinement of neritic phytoplankters in the summer period to waters over the shelf. He also indicated that the distribution of neritic species was limited to waters of the shelf; whereas oceanic species found favorable conditions for development in littoral and in oceanic waters. This explains the large quantity of oceanic phytoplankters found in the neritic community.

The data which we obtained on the distribution and abundance of dominant species of phyto- and zooplankters confirms the normal distribution of planktonic communities in the Bering Sea (Fyomina [illegible]; Heinrich [illegible]).

Among the important distinguishing characteristics of the communities which we observed was the time-variability of the species composition and abundance of the plankton in the shallow part of the [illegible] area, compared to the situation in deep water. This, evidently, is the result of the more active dynamics of the water in the deep part of the [illegible], in the zone of influence of the [illegible] current. In the shallow area, the current is very weak and probably cannot significantly change the characteristics of the community in a given zone by way of introducing

[illegible]

IV. [illegible]

Weather Conditions and Atmospheric Chemistry

The comparison of mean surface pressure charts for August 1977 (Fig. [illegible]) with mean data for many years showed that over the northern-western part of the Pacific Ocean the pressure was somewhat higher than normal. According to historical data the core of the Northern-Pacific anticyclone is located at 40°N, 1[illegible] but in August 1977 there were two cores of high pressure: one - at 40°N 180° (P-1020 mb) and the other near the coast of North America. In August 1977 the pressure over the Bering Sea was normal.

Cyclonic activity was weak in the first half of August. The region of cyclogenesis was near Baikal and Japan Islands and moved along a northern trajectory, i.e. from Japan Islands to the Sea of Okhotsk to the North-East, to the northern part of the Bering Sea. The direction of cyclone movement was determined by a high-level baric-field. The existence in the middle of high-level Pacific reach oriented to the Sea and western position of the high-level depression were responsible for the cyclones appearance over the Bering Sea (Fig. [illegible]).

These cyclones as a rule were poorly developed. As to their structure, they were low baric formations and in AT50 chart they were not detected. Their movement velocity changed within the limits of 15 - 20 km/h.

The weather in the Bering Sea was determined by two factors: Cyclones moving somewhat to the North of the test-site and Northern-Pacific anticyclone reach.

Continuous change of weather resulted from cyclones reaching the Bering Sea. For example on the 5th of August the northern part of the Bering Sea was reached by a cyclone with core pressure 1020 mb, the frontal system, associated with it, crossed the region of work and caused enhancement of wind to 9 - 10 m/sec and rain. During the following days the weather was quiet because the high pressure reach was formed.

According to data obtained in other expeditions of scientific research vessels of the Gidrometsluzhba SSSR (USSR Hydrometeorological Service), the average concentration of Pb^{214} over distances of tens to hundreds of kilometers was of the order of magnitude of 30×10^{-15} curies per liter; and over distances of hundreds to a few thousand kilometers, 5×10^{-15} curies per liter; while in the open ocean it was 1.5×10^{-15} curies per liter. Pb^{212} was observed only at distances up to 1000 km.

As is seen from Table 7, the average concentration of Pb^{214} varied over the range of 2.35 to 11.0×10^{-15} curies per liter, and this is in approximate agreement with the thousand-kilometer distance traveled by the air mass to the point of sampling from its contact with dry land.

Through the medium of facsimile synoptic surface maps, reverse trajectories were plotted for the determination of the travel paths of the air masses. Facsimile maps were taken while onboard the ship four times per day, at 2400, 0600, 1200 and 1800 hours Greenwich time. Each time, the reverse two-day trajectory was plotted. In Fig. 64, trajectories are shown for each day of the study in the study area. The number next to each trajectory indicates the date of arrival of the air mass at the point where the ship was located. Thus 30 signifies that on the 30th of July the ship encountered air masses which up to that point had traveled on the trajectory next to which this number 30 appears. The point in the middle of this trajectory marks the spot where the air mass was located in the 24 hours before the time of contact with the ship, and the end point of the trajectory marks the location of that air mass two days later. Some trajectories are not shown, since facsimile maps were not prepared onboard the ship in that period during August 3 to August 10, and August 12-13; and two of the trajectories were for only one day (during August 7 and August 11).

It is interesting to compare the plotted trajectories with the data on the content of natural radioactivity in the atmosphere. It is seen from Table 7 that increases in the content of Pb^{214} and Pb^{212} were noted on the 4th, 8th, 9th, 10th, and 11th of August. The average wind speed during the period of the study on the polygon was 6 m/sec, or 20 km/hr, i.e., the length of the trajectory

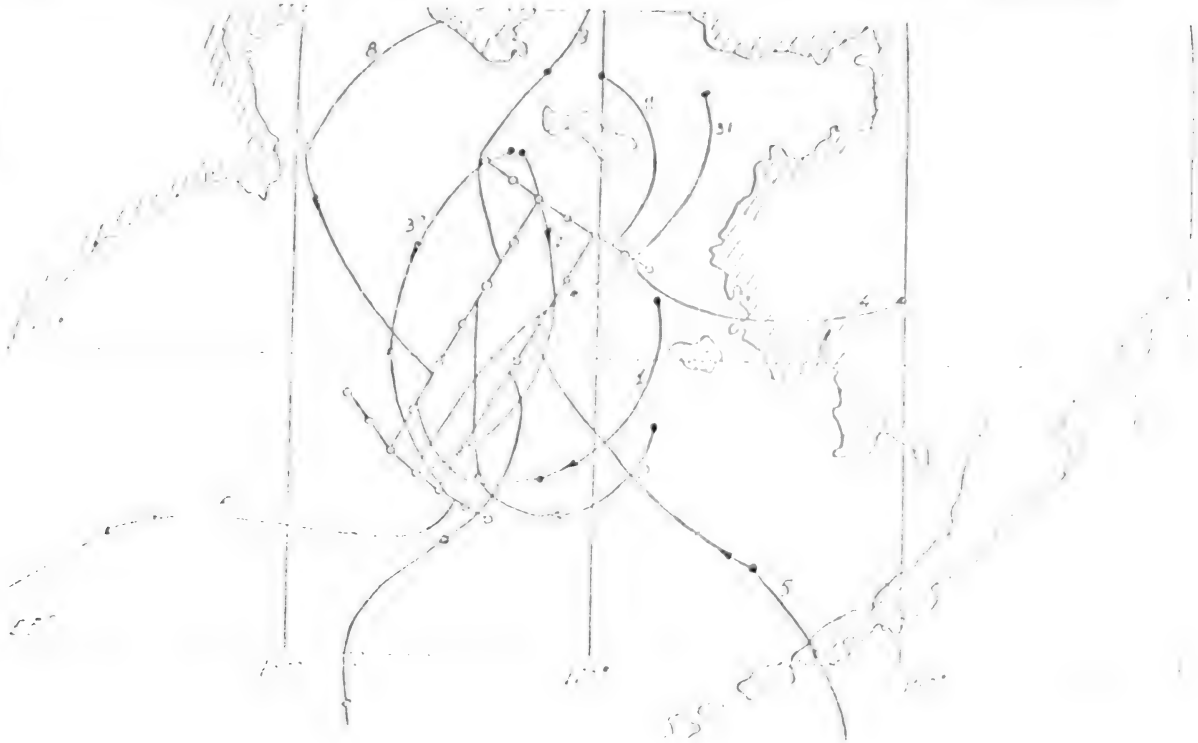

Figure 68. Trajectories of airmasses in the Bering Sea during the period July 30 to August 11, 1978.

[illegible]

[illegible] This fact suggests that [illegible] sulfur [illegible] in the [illegible] of the [illegible] largely [illegible] of natural processes. One of the possible paths [illegible] may be emission of natural sulfur compounds from the sea water and their subsequent oxidation directly in the atmosphere. Sulfur dioxide may be formed as an intermediate product in the oxidation process:

[illegible]

[illegible]

At present it is [illegible] [illegible] [illegible].

It is interesting to compare the concentration of sulfur dioxide which we obtained with those of other authors. In Table [illegible] concentrations of sulfur dioxide in the [illegible] atmosphere which were obtained by various authors have been collected.

[illegible] that the characteristic concentrations of sulfur dioxide for the studied regions of the earth's [illegible] are in the order of tenths of a microgram per cubic meter. Some [illegible] concentrations were observed for the northwest region of the Atlantic [illegible] the influence of anthropogenic [illegible] in the northeast states of the USA.

Table [illegible]

Literature data on the concentrations of Sulfur Dioxide in the Ocean Atmosphere

Year	Region of Measurement	Author	SO_2 Concentration (µg/m³)
[illegible]	South Pacific and Indian Ocean	[illegible] et al.	[illegible]
[illegible]	North Atlantic (western part)	Flyger et al.	0.05-3.04 / 0.77
[illegible]	Pacific Ocean (central part)	Ryaboshenko et al.	[illegible]
[illegible]	North Atlantic (eastern part)	Prahm et al.	[illegible]
[illegible]	Bering Sea	This work	[illegible]-0.55 / 0.19
[illegible]	Pacific Ocean (northern part)	This work	0.03-0.7[illegible] / [illegible]

[illegible] of aerosols over the surface of the ocean is [illegible]. The element magnesium far from the continents [illegible] origin; accordingly, the fraction of oceanic [illegible] in the complex was determined based on the concentration of magnesium, the concentration of which in sea salt is [illegible]. Starting from the data on the concentration of magnesium in the air -- [illegible]. It was determined that the content of sea salt in the layer of the atmosphere near the water is [illegible] of the total aerosols present. The remainder of the aerosol is comprised of continental dust. In Fig. [illegible] the direct relation between the content of aerosols and the content of sea salt in the air is seen. The average concentration of continental aerosols in the central part of the Bering Sea is around [illegible] $\mu g/m^3$. The concentration of metals near the surface of the Bering Sea does not differ from concentrations obtained in various other regions of the Pacific Ocean which are appreciably removed from the continents.

The average concentrations of metals (at various depths) in the surface waters of the studies polygon in the Bering Sea were close to their average concentrations in sea water (Robertson et al. [illegible]; Shutz and Turekian, [illegible]).

The results obtained for the concentration of metals in the atmosphere and in sea water agree, in general, with the data of other authors for "clean" regions of the ocean, and may be regarded as an approximation of the background levels of the contents of these elements in the study area.

[illegible]

[illegible]

[illegible] Drakovis and Radosavlis, [illegible].

The concentration of hydrocarbons in the test area averaged: atmosphere [illegible] sea water -- surface microlayer [illegible] ug/l; [illegible] ug/l, [illegible] ug/l. The coefficient of enrichment $K_{[illegible]}$, i.e. the ratio of hydrocarbon concentration in the surface microlayer to the concentration in water at the surface was [illegible] for the first stage (stations 1-[illegible]) and [illegible] for the second stage (stations [illegible]).

As was shown earlier, an increase in plankton led to an increase in the total quantity of hydrocarbons in sea water. This fully justifies the conclusion that they hydrocarbons in Bering Sea waters are of biogenic origin. This is also indicated by the high concentrations of hydrocarbons in these waters, which are associated with the bioproductivity of this region, since the hydrocarbon concentrations in the central ocean regions are around [illegible] times lower than in the area under study. On the other hand, the chromatogram in Figure [illegible] had a large "bulge",

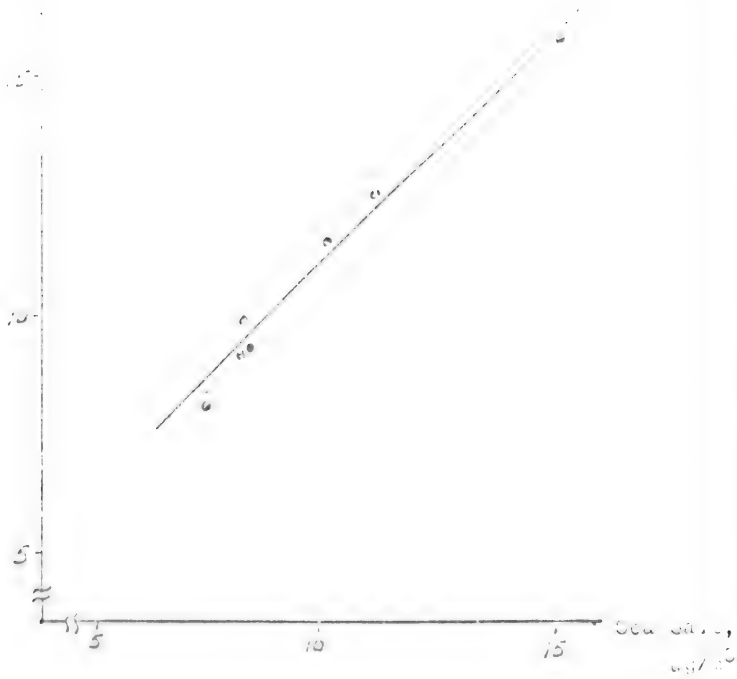

Figure 69. Relationship between content of aerosols in the air and the concentration of sea salt /in the air/ over the surface of the water.

which means that in addition to normal alkanes which appear as spikes, there are also a large number of undivided hydrocarbons, a fact which may be attributed to oil pollution. The problem of determining oil pollution against the background of hydrocarbons occurring naturally in sea water is a complicated problem and as of now there are no unambiguous criteria for recognizing oil pollution.

The results we obtained for the content of hydrocarbons in the atmosphere may be compared with the data of other authors for the Pacific Ocean. Thus, for samples taken in the Hawaiian Islands in 1969, the content of organic matter in the atmosphere extracted by filters with chloroform was [illegible] ug/m³ (Shabad et al. [illegible]). According to other data the content of hydrocarbons -- also extracted by chloroform -- in the Pacific Ocean near the equator was [illegible] to [illegible] ug/m³. The hydrocarbon concentrations we obtained over the Bering Sea may also indicate that this region may be assigned to the clean areas of the open ocean.

Let us consider the question of the source of organic aerosols in the layer of atmosphere adjacent to the water. As shown above, the content of continental mineral aerosols in the central regions of the Bering Sea equals [illegible] ug/m³. But the content of organic matter in aerosol above the continent varies between 5 and 10% of the value for total dust, i.e. the value for organic aerosols of continental origin above the region under study equals [illegible] ug/m³. According to our data the total content of hydrocarbons above the

[illegible], which indicates the [illegible] of organic aerosols [illegible], just as mineral aerosols, is of oceanic origin.

In aerosols formation, no fractionation between macro-elements of sea water (Na, Mg, Ca) occurs, i.e. their coefficient of fractionation equals one, when determined as:

$$F = \frac{\left(\frac{C_i}{\sum M_i} \right)_{air}}{\left(\frac{C_i}{\sum M_i} \right)_{water}}$$

where C_i is the concentration of the macroelement in water or air. However, if C_i is taken as the concentration of hydrocarbons, the coefficient of fractionation will equal [illegible], i.e. in the formation of oceanic aerosols a strong enrichment of hydrocarbons occurs in relation to oceanic salts.

Most likely this enrichment occurs because of the surface microlayer, which is one of the most important but poorly studied regions of the ocean environment. In the surface microlayer an increase in the concentration of hydrocarbons, polychlorinated biphenyls and certain metals was observed. This may occur both because of transport of these substances to the surface of the ocean by gas bubbles and because of precipitation of pollutants from the atmosphere onto the surface of the water.

There are various estimates of the thickness of this layer -- from a monomolecular [illegible] to [illegible] u. The present method of sampling permits a layer of sea water around [illegible]-[illegible] u thick to be

samples. [illegible]

denudation [illegible]

water [illegible]

[illegible] from [illegible].

Let us suppose that the forming [illegible] aerosols are covered by a surface film and let us calculate the coefficient of fractionation for the following thicknesses: [illegible], [illegible], [illegible] and [illegible]. We will also assume that all the hydrocarbons which we sampled in the [illegible]-thick layer are in fact concentrated in a film of the above-mentioned thickness. If the concentration of hydrocarbons in the surface layer is [illegible] g/l, their concentration in the films of lesser thickness will be:

when [illegible]

[illegible]

The distribution of [illegible] saline aerosols by mass and by number of particles is shown in Figure [illegible]. As this figure shows, the bulk of aerosols lie in the region of [illegible] in size. Thus, assuming that the forming [illegible] particle contains the [illegible] in [illegible] equal the [illegible] of the aerosol [illegible] the [illegible] of magnesium in sea water, we can calculate the [illegible] of hydrocarbon content [illegible] formula:

$$\frac{[illegible]}{[illegible]} = \frac{[illegible] + (N_1.p.s.d) + (N_2.p.s.d) + (N_3.p.s.d) + (N_4.p.s.d) + (N_5.p.s.d)}{(N_1.P_{Mg}.v) + (N_2.P_{Mg}.v) + (N_3.P_{Mg}.v) + (N_4.P_{Mg}.v) + (N_5.P_{Mg}.v)}$$

where: S_{h} = the concentration of hydrocarbons in air;

S_{Mg} = the concentration of magnesium in air;

N_1, N_2, N_3, N_4, N_5 = the portion of aerosols with diameters of 0.3 u, 0.6 u, 1.[illegible] u, 2.5 u and 5 u respectively;

s = the area of coverage of the film of aerosols with the above-mentioned dimensions;

d = the thickness of the film;

v = the volume of particles of various diameters;

P_{Mg} = the density of magnesium in water ($1.3.10^6$ ug/l).

The coefficient of fractionation for hydrocarbons on the assumption that all ocean aerosols are covered by an organic film from [illegible] to [illegible] u which is constant at [illegible].

Thus in order to obtain a coefficient of fractionation of [illegible], it is necessary to assume the formation of purely organic aerosols which will make the basic contribution (over [illegible]) to the suspended organic matter in the layer of atmosphere adjacent to the water.

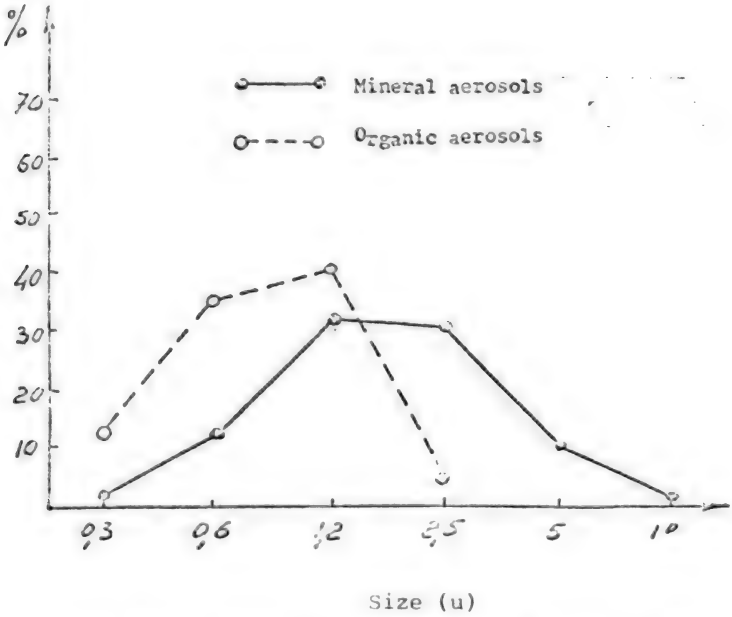

Figure 70. Variation in particle size of mineral and organic aerosols.

Gung presents a photograph of the mechanism of ocean aerosol formation in the absence of sea waves. As was shown, these aerosols are formed as the result of the rupture of gas bubbles 50-1000 u in size rising to the surface. As the bubbles rupture, a great number of aerosols form both from the center and the margins of the bubble. Thus, it follows that the chemical composition of the aerosols formed from the center of the bubble is characteristic of the composition of sea water. If we assume that the surface of the water is covered by a film with an increased content by hydrocarbons, then as it ruptures into bubbles, purely organic aerosols are formed, and these make up the basic bulk of suspended organic matter in the layer of atmosphere adjacent to the water.

The literature contains data on the size of particles which may form when a film breaks up. (In laboratory conditions particles of 0.4 to 1 u in diameter are formed in the break up of an organic film several molecules thick). Figure 70 sets forth the spectrum of organic aerosols above the sea surface obtained in the Bering Sea. It is characterized by the fact that it was obtained in a coastal zone which is comparable in bioproductivity to the Bering Sea and the bulk of suspended organic matter lies in the aerosol diameter range of 0.3 to 2 u (Alshiam 1968).

Thus, it may be concluded that the organic aerosols above the sea surface are formed from the surface microlayer. The chemical composition of the suspended organic matter in the ocean

atmosphere should correspond to the surface film and for the most part be between 0.2 and 1 u in size. Suspended organic matter less than 0.1 u in size will characterize that portion of the aerosols which travels long distances and in particular is carried into the ocean atmosphere from the continents.

The mechanism described above for the formation of organic aerosols may be a source of atmospheric pollutants in the coastal zone, the surface waters of which are at present severly polluted. If the surface of the water is covered with a film of oil, aerosols will be formed in the air from this film and transported over large distances, polluting the pure waters of the ocean.

The content of benzo(a)pyrene at the sea surface was 0.014 ug/m^3, and in the surface microlayer it is 0.125 ug/liter. The concentration coefficient for benzo(a)pyrene in the central regions of the Bering Sea is $K_{conc} = 9$. The values of the concentrations of benzo(a)pyrene in the waters of the Bering Sea were relatively high, when compared to literature data and the concentrations of benzo(a)pyrene in clean waters are within the range 0.001 to 0.01 ug/liter.

As already discussed above with regard to the metals, plankton is an accumulator of polluting substances. Our measurements showed that the content of benzo(a)pyrene per kg of dry weight of plankton is approximately 0.622 mg; calculated on the basis of the raw weight this would be around 0.04 mg/kg. Thus

the concentration of benzo(a)pyrene in plankton is approximately 2900 times higher than in the water. The values of the concentrations of benzo(a)pyrene in biomaterials vary over wide ranges. According to the data, the concentration of benzo(a)pyrene in plankton can vary from 0 to 5 mg/kg of dry weight. The following data on the content of benzo(a)pyrene in plankton is: in the Black Sea, 0.107 mg/kg of dry weight; and in the Japanese Sea, 0.121 mg/kg of dry weight. These plankton samples were collected 200 m from the shore. According to measurements the content of benzo(a)pyrene in plankton of the Mediterranean Sea is 0.4 mg/kg raw weight. Thus, the concentration of benzo(a)-pyrene in plankton of the Bering Sea is five times higher than in plankton of the Black or Japanese Seas, but is an order of magnitude lower than in plankton of the Mediterranean Sea (Adrakov pers. comm.).

The Japanese, Black, and Mediterranean Seas are strongly polluted with petroleum products and are located in the vicinity of major industrial regiosn. Therefore the elevated concentrations of polycyclic aromatic hydrocarbons in plankton of these seas is completely explainable. However, the question of the source of the pollution of the Bering Sea with polycyclic aromatic hydrocarbons is not as yet resolved.

The average concentration of benzo(a)pyrene in the atmosphere of the Bering Sea over two samples was 0.15 ng/m^3. This is a

small number of air samples on which to base any kind of generalization, nonetheless this number gives an approximate idea of the concentration of benzo-a-pyrene in the air over the sea surface.

There are practically no data available on the content of carcinogenic hydrocarbons in the oceanic atmosphere. Data were presented on the content of polycyclic aromatic hydrocarbons in the atmosphere based on sampling of aerosols from the shore area (i.e., offshore area of central Norway. A relation was established between the concentration of hydrocarbons and the place from which the air mass originated. The concentration of BP varied within the limits [illegible] ng/m³. The lowest concentration of BP were associated with air masses which had come from the north ([illegible] to [illegible] ng/m³). The highest concentrations were observed in air masses which had come from industrial regions of Western Europe (Alsheim 19[illegible]).

In the Bering Sea the proportion of the carcinogenic hydrocarbon benzo-a-pyrene of the total amount of hydrocarbons in the water was [illegible], and the proportion of benzo-a-pyrene in organic aerosols over the water surface was also approximately [illegible]. As indicated earlier, the main source of hydrocarbons over the oceanic surface is the ocean itself, and the equal content of benzo-a-pyrene in the hydrocarbons located in the water and in the air indicated that the source of the benzo-a-pyrene in the atmosphere of the central regions of the Bering Sea is also the water.

In the lower molecular weight hydrocarbon data a major difficulty arises from the fact that the stations were sampled twice, with a time period of approximately [illegible] days between profiles. In some cases, the results between profiles and in others the agreement was very poor. The temperature data in those cases of disagreement indicate that the mixing layer and temperature profiles or the water movements were greater than believed. If these were strong, then localized variations, therefore, [illegible] explaining the variation in the hydrocarbons. If it [illegible] we were in the proper location, then other processes or locally generated variations must be accepted as the case for the discrepancies. In any case, we have treated the stations not as duplicates but as individual stations.

The distribution of C_1–C_4 hydrocarbons in the water column was highly variable, particularly in shallow water environments. The variability arises from the various modes of production: biogenic; petrogenic (sediments); photochemical (dissolved organic material reactions). There have been several attempts to establish ratios of these hydrocarbons to indicate possible sources. In this particular case, it will be necessary to compare these ratios to the [illegible] data.

In the upper layers of the ocean ([illegible] from [illegible]) [illegible], pronounced concentration peaks were found, with the olefins generally being higher in concentration than their saturated homologs. During this [illegible], [illegible] considered as

"open ocean" fit the general pattern. This nonhomogeneous distribution suggests the existence of processes occurring at rates possibly faster than physical mixing rates. Laboratory experiments with marine organisms have shown that unsaturated hydrocarbons such C_2H_4 and C_3H_6 are produced while the saturated homologs are not. The existence of similar phytoplankton distributions in the open ocean suggests that there may be some correlation between these two parameters.

Methane concentrations in the "open ocean" segment do not show any subsurface maxima. In light of previous data, this was not an unusual situation. Ethane and propane decrease quite rapidly with depth. Again, this fits the general pattern of the "open ocean". The consumption mechanisms that decrease the ethane and propane are unknown.

In the shallow water environment, the values were quite different but not unexpected. The shallow water portion of the cruise track was characterized by an extremely strong thermocline which results in an equally strong pycnocline. This pycnocline effectively places a barrier between the mixed layer (10 meters deep) and the rest of the water column. Above this cap, the values for all the light hydrocarbons was approximately that of the "open ocean" stations. However, below this cap, methane, ethane, and propane increase by a factor of 2, 3 or more. At first glance, there appears to be little if any flux across

this carrier. Not having available closely spaces sampling, restricts our interpretation relative to realistic flux calculations across this pycnocline.

These high values for saturated hydrocarbons persist out into the immediate zone at [illegible] depths. This data indicates the need for "open ocean" stations permitting determination as to the extent of this shallow shelf water. The general current circulation is in a counterclockwise direction. One could expect that the concentrations in the westerly portion of sampling pattern may be the result of in situ production and/or possible advection from the eastern portion of the track. Data is needed reflecting some local current measurements to make meaningful predictions of possible source locations and production rates.

The unsaturates in the shallow water behave somewhat similarly to those in the "open ocean" stations. The concentrations were relatively similar and subsurface maxima were present. In several cases, the subsurface maxima occurred below the pycnocline. This was very unusual and at the present time cannot be explained.

The intermediate zone is exactly that; the change over from the shallow water environment to "open ocean" as indicated in the profiles. Again, the changes which were present were not too different from what one would expect from this type of environment providing sufficient "time-gathered" data substantively reinforces these findings.

Carbon monoxide distributions were extremely complex. It has been shown that the production of carbon monoxide is controlled by the amount of radiation which is available. During this cruise, stations were occupied at numerous times of the day and under a number of different weather conditions. Because of such variance, it is difficult to give any insight regarding the distribution of this trace gas except in very broad statements. During those times of restricted incident radiation, carbon monoxide values at those stations were much less than that found at stations with high incident radiation. Phytoplankton populations play an important part in carbon monoxide production (i.e. high primary productivity, high CO_2 concentrations). The carbon monoxide values decrease rapidly with depth in all cases. This follows the pattern that has been found throughout the world oceans.

This initial survey indicates the area is not vastly unique from most ocean environments. There is the possibility that some of the high concentrations of saturated compounds may be transported from the Norton Sound area. The role of coastal pollution and/or ocean traffic is still obscure but must be considered in future sampling plans. This area has known petroleum seeps and these could very possibly be an important source for the present sampling area. The unsaturated compounds exhibit some curvilinear maxima but the causes must await further biological data analysis interpretation.

Conclusion

[illegible]

inters. The International Pacific Halibut Commission reported that the movement of halibut onto the shelf decreased steadily from 1963 to a minimum in 1972 (Best 1977). Their return to the shelf in 1977 was the strongest in the last few years.

The areal extent of ice cover on the Bering Sea is related to wind and air temperatures (Konishi and Saito 1974). The cooling trend can be viewed in terms of the area of ice cover in the Bering Sea in time (McLain and Favorite 1976). N. O. A. A. ice charts developed from satellite photography are routinely analyzed at the Lamont Doherty Geological Observatory. A graph of ice cover in the Bering Sea region with 80°N-50°N appears in Figure 73. The data for this figure include open water within the pack ice boundary and all categories of ice through fast ice. This figure indicates that the apparent cooling trend noted by McLain and Favorite (1976) continued through 1976 when maximum ice cover was observed. A sharp reversal of this trend was noted in 1977 and continued through 1978. The temperature regime sampled during this study was the result of dramatic warming following a relatively severe winter. The steep thermoclines observed over the shelf that resulted from this pattern impose restrictions on the transport of nutrients to the euphotic zone from the bottom water, as evidenced in the vertical distribution of nutrients in shelf waters. Similarly the transport of particulate organic matter formed in the euphotic zone to the benthic community is restricted [illegible] in the presence of thermocline associated chlorophyll maxima.

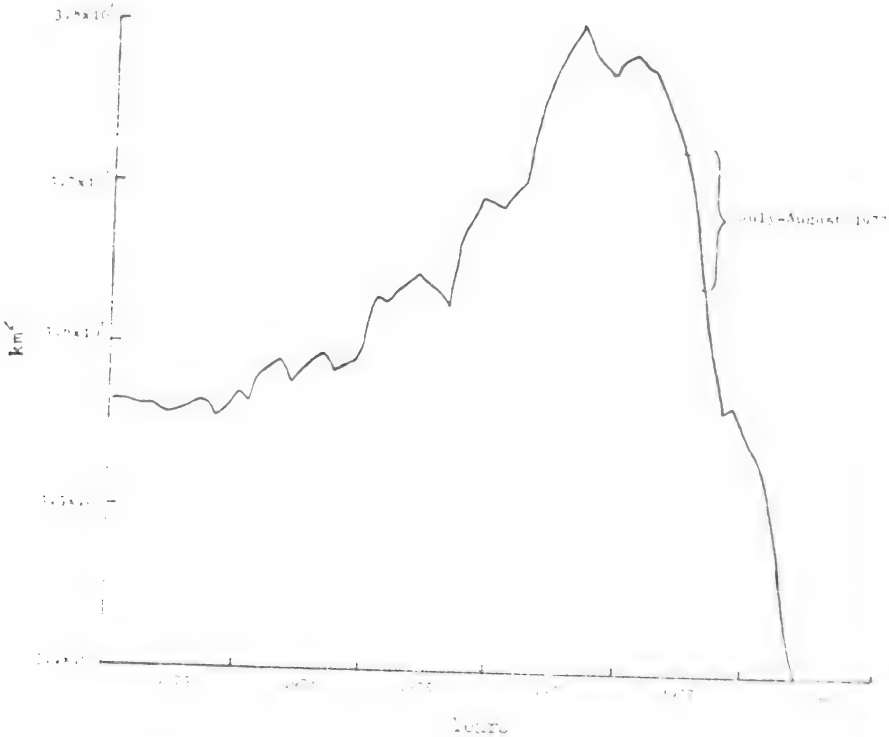

Figure 71. Areal extent of ice cover in the Bering Sea 1973-1978
Area of ice cover within 80°N-50°N (as km²) and year.
Indicated in figure is the period of study.

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Light

The distribution of light extinction properties in the shelf was examined by Arsenyev and Voytov [illegible] and Kawara [illegible]; the former used secchi disk measurements while the latter used a turbidity meter. Kawara noted a distinct turbid layer associated with the thermocline in the continental shelf region. In coastal areas the turbidity was vertically uniform due to increased mixing. Arsenyev and Voytov [illegible] summarized secchi disk measurements of transparency taken by Soviet researchers in the period [illegible]. Their data were converted to extinction coefficients for comparison using the formula from Poole and Atkins [illegible] which assumes that 10% of surface light intensity remains at the depth that a white disk disappears from view:

$$K_e = \frac{1.7}{SD}$$

where SD is the depth of secchi disk disappearance and K_e is the extinction coefficients in units of the reciprocal of the secchi depths units.

The areal distribution of extinction [illegible] data derived from photometer extinction coefficients and their comparison to those of Arsenyev and Voytov [illegible] are shown in Figure [illegible]. The values from Arsenyev and Voytov's work are in general agreement with those recorded here and indicate increasing light penetration towards the continental [illegible]. The [illegible] increase in the depth of the upper mixed layer on the continental [illegible]

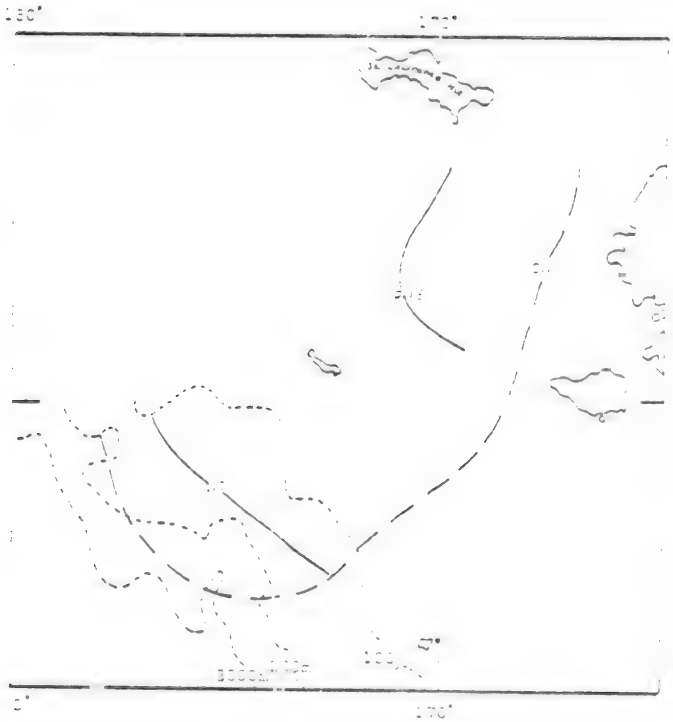

Figure 72. Distribution of extinction coefficients and comparison to those of Arsenyev and Veytov (1968). Light extinction coefficients isopleths from this study are indicated by solid line. The broken isopleth is from data by Arsenyev and Veytov (1968). Light extinction coefficients were lower below the broken isopleth.

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slope is approached is seen as an important characteristic providing a potential for greater productivity on an areal basis near the continental slope.

Abmient light in this region varies over two orders of magnitude from summer to winter solstice. A land based weather station located proximal to 60 N at Bethel. Alaska reported a mean (based upon nine years of data) daily solar radiation of 22 langleys for December and 454, 576 and 252 langleys for June, July and August, respectively (U.S.D.C. Weather Service 1964). Reference cell photometer readings were generally comparable to readings taken the following September, 1977 with the same production in the Bering Sea light is apparently limiting (McRoy and Goering 1976). However, light limitation is not apparent during summer months in the upper mixed layer as evidenced by large decays in nutrient pools at the continental slope where the mixed layer was the deepest (20-35m).

Nutrients

On the average, phosphorous and nitrogen are found in seawater in an atomic ration of 1:15 and are utilized by plankton in a ration of 1:16 (Redfield et al. 1963; Ryther and Dunstan 1971). Evidence is presented here that nitrogen and phosphorous are removed from Bering Sea water in a mean 18.9:1 ratio and in light of ambient concentrations that nitrogen would ultimately be limitied to phytoplankton with continued decay at that proportion. Silica

which usually varies in proportion to nitrate in seawater (Redfield et al. 1963) is indicated as doing so here and a mean 1.1:1 (N:S) proportion in their decay is noted. The major source of these nutrients to the shelf below St. Lawrence Island appears to be the Aleutian Basin which in turn is fed to North Pacific water upwelled through the Aleutian Passes (Kelly and Hood 1971; Sugiura 1974).

While the periodic influx of water to the lower shelf and continental slope from the deep basin appears to be an important mechanism for maintenance of the nutrient supply in the euphotic zone, no such large scale supply mechanism is indicated in the shelf region to the north of St. Matthew Island. The maintenance of the cold water area southwest of St. Lawrence Island indicates the lack of large scale transport from the warmer, nutrient rich waters to the south. Further, the severe pycnocline found in this area would limit the movement of nutrients regenerated at the bottom into the euphotic zone. Nutrient cycling above the thermocline would appear to play an important role in maintaining productivity here during summer until the dissipation of the thermocline in autumn. Nishizawa and Tsunogai (1974) estimated that two-thirds of particulate organic carbon in the Bering Sea is decomposed in the surface layer while the remainder drops to deeper water. Zooplankton would accelerate the cycling of nutrients within the mixed layer. Phosphate dissolution from

zooplankton fecal pellets and soluble nitrogen excretion by zooplankton is rapid (Harvey 1974). A variety of bacteria and some phytoplankton hydrolyze organic compounds and release inorganic phosphorous at rates substantially faster than for the mineralization of organic nitrogen (Parsons et al. 1977). Nelson and Goering (1977) demonstrated that silica dissolution from biogenic silica without an organic coating proceeds at a rate that could support maximum silicic acid uptake rates. The silica dissolution process would be enhanced by grazing. The decrease in euphotic zone integrated chlorophyll is presumed to be the result of zooplankton predation. Nitrogen excretion can be considered proportional to the metabolic rate of zooplankton (Steele 1974). Evidence of ammonia and silica (as silicates) production can be seen in Figure 79 as associated with stations where chlorophyll loss is evident.

Nitrogen cycling in the Pacific Ocean was examined by Goering 1968; Wada and Hattori 1971; Miyazaki et al. 1975; Goering and Dugdale 1966; and Harrison 1978. Generally, the rate at which ammonia and nitrate are assimilated is dependent upon their natural abundance; phytoplankton from high nutrient areas tend to demonstrate higher half saturation constants. McRoy et al. (1972) suggested, based upon ^{15}N uptake measurements, that generally less than 50% of inorganic nitrogen is assimilated by phytoplankton as nitrate in the Bering Sea. Ammonia is the preferred source of nitrogen to phytoplankton. Ammonia usually results from the short term

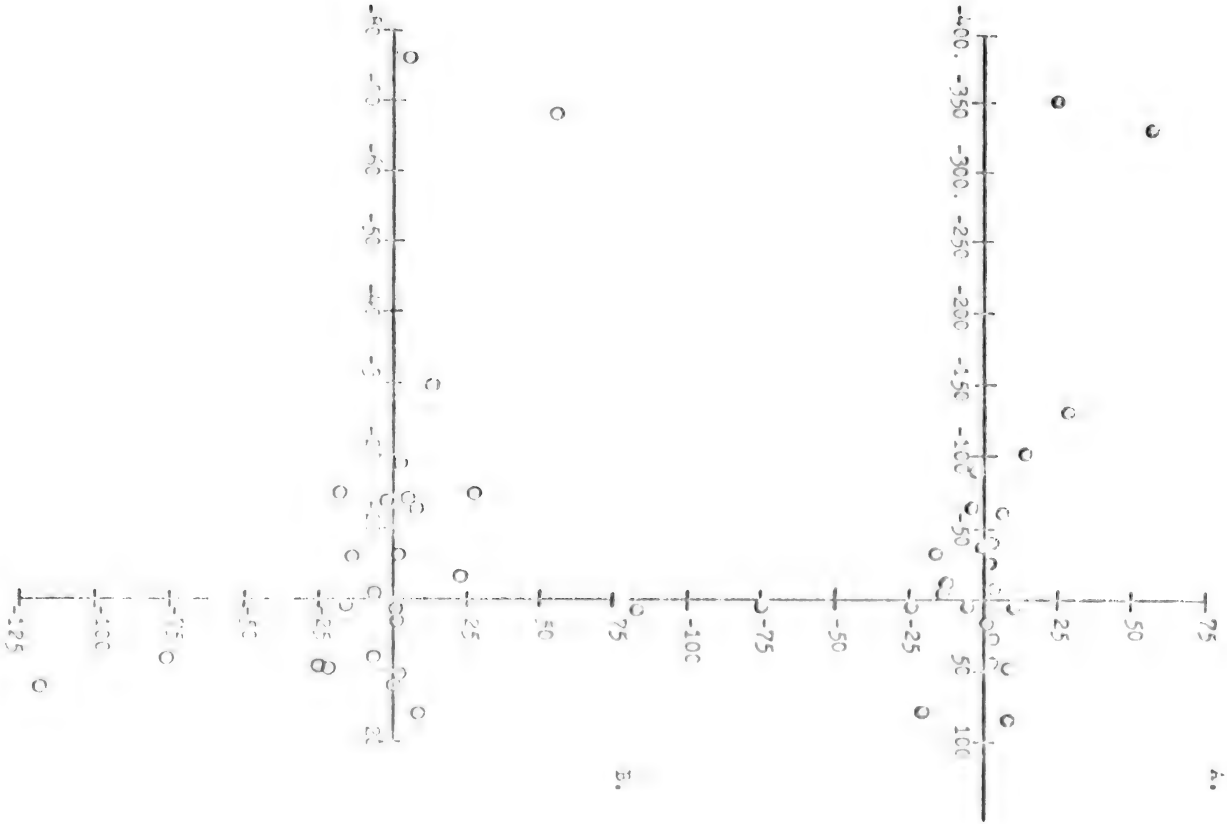

Figure 73. Relationship between the change in chlorphyll a concentrations and changes in ammonia and silica as soluble silicate concentrations.

regeneration of nitrogen and in the Bering Sea does not represent an advected source of "new" nitrogen. Generally, the advection of nitrogen from deep waters in nitrate incorporation by nonchlorophyll-bearing ammonia-producing heterotrophic bacteria is a mechanism that might account for a portion of the large decay in nitrate that occurred between samplings on the southern transect. Such a mechanism was suggested by Hattori and Wada (1974) and Wada and Hattori (1971).

Nitrite is an important tracer of the nitrogen cycle. Areas rich in nitrite are associated with areas of active nitrogen cycling (Hattori and Wada 1974; Wada and Hattori 1971). The highest euphotic zone integrated concentrations of nitrite were found at stations in the region of the Zhemchug Canyon along the southern transect and ranged from 2-8 ug-at/m^2. Some nitrite production was evident (Table 24) at stations at the northern end of the sampling grid where a decrease in chlorophyll a concentrations and an increase in ammonia concentrations were observed and probably result from the oxidation of ammonia by nitrifying bacteria.

Circulation

The general counter clockwise gyre reported for the Bering Sea basin (Hughes et al. 1974; Takenouti and Ohtani 1974) is evident in the dynamic topography of the shelf area, particularly below St. Matthew Island. The northward flow that Natarov (in Hughes et al. 1974) indicated as passing to the east and west of St. Lawrence

Island is also apparent. However, a southward moving counter current towards the coast of Alaska in the northeast corner of the 25 dbar velocity field is also indicated. Although caution should be exercised when interpreting calculated flows in shallow areas, the comparatively low salinities (29‰) in this area provide support for the presence of a countercurrent. This countercurrent was also indicated in the dynamic topography developed from the second sampling. The stability of this feature is not known but indicates that transport from Norton Sound (the Yukon River receiving body) may be of at least periodic importance to the lower shelf area. The general westward flow over the shelf is probably a more persistent feature in the area. Similar evidence of a westward baroclinic flow was provided by Muench (1976) in data from a hydrographic transect from Bristol Bay to Norton Sound.

If one considers that the cross sectional area between Cape Navarin on the Siberian coast and Cape Tomanoff on the Alaskan coast is on the order of 90 x 10^6 m^2 (calculated from N.O.A.A. chart 514) and that flow through the Bering Strait is 1.4 x 10^6 m^3 /sec (Coachman and Aagaard 1966), then an average velocity of 1.5 cm/sec would be expected through this area. Calculated velocities in the region of the cold water mass southwest of St. Lawrence Island were substantially less than 1.5 cm/sec while others on the northern transect were in that range. The persistance of the cold water mass is probably related somewhat

to divergence of the northward flow and it generally appears that this area is less effected by transport.

The implication of baroclinic flow at the continental shelf in relation to possible periodic upwelling as a result of interaction with the wind field was considered by Muench (1976) in Bristol Bay, however he stated that upwelling had not been documented in this area.

The velocity vectors referenced to the 50 and 75 dbar surfaces along the continental slope indicate a northward movement of water up the Zhemchug Canyon and onto the shelf. This feature was observed in dynamic topographies formulated from data from the first and second samplings of the area. The southward moving flow indicated in the western portion of the canyon (between stations 3-4) at the 25 dbar level from the first sampling was noted at the 75 dbar level the second time. The direction of flow at the eastern portion of the canyon (between stations 2 - 3) which was to the north in reference to decibar levels to the 75 dbar on the first sampling was to the south at the 25 dbar level on the second sampling. This estuarine-type circulation indicates upwelling but due to the nature of the calculations and the relatively shallow depth sampled they do not present by themselves a strong case for upwelling.

Upwelling Phenomena

The classic upwelling areas occur along the eastern boundaries of oceans in the region of the trade winds (Newman and

Pierson 1966; Redfield et al.1963). Upwelling is usually maintained by the movement of deep water to the area of upwelling to replace surface waters that have been moved by wind (Redfield et al.1963). Upwelling areas are the most productive areas of the world oceans (Parsons et al.1977). Ryther (In O'Reilley et al.1976) measured 11.9 g C/m^2-day in the Peruvian coastal upwelling using a ^{14}C technique with a 24-hour incubation period. Kelly and Hood (1971) suggested local upwelling near the eastern end of St. Lawrence Island in relation to observed high CO_2 water concentrations (425 ppm) relative to air (317 ppm). Upwelling at the sills of the Aleutian Passes also was suggested by Hood and Kelly. Upwelling along the Aleutian Passes is due to convergent currents and the interaction of bottom topography and is evidenced in high concentrations of nitrate and phosphate from the deep water source (Hood and Kelly 1974). Upwelling in the Bering Sea although suspected has not been documented.

The movement of deep water into upper layers results in the formation of parallel isohalines and nutrient isopleths (Redfield et al.1963). Evidence of upwelling is presented in the nitrate and salinity isopleths from the north to south transect extending into the Zhemchug Canyon (Figure 76). In upwelling areas the major source of nitrogen to phytoplankton is nitrate (Redfield et al.1963). The euphotic zone integrated nitrate values at stations 1 - 8, 24 and the bathmetry of the continental slope

and the Zhemchug Canyon appear in Figure 77. McRoy et al.(1972) measured nitrogen and carbon uptake in the Bering Strait in 1967. Their measurement of primary production at 8 g C/m^2-day is the highest reported for the Bering Sea. Nitrogen and carbon were taken up in a 7:1 ratio and 77-89% of the nitrogen was assimilated as nitrate.

Hattori and Wada (1974), in the development of a large scale nitrogen budget for the Bering Sea, employed a carbon to nitrogen ratio of 7:1 in their calculations based upon ^{14}C and ^{15}N uptake measurement. Redfield et al.(1963) proposed a relatively constant ratio of carbon to nitrogen for plankton as 5.5:1. Employing a ratio of C:N as 7:1 in estimating carbon fixation from observed nutrient decays resulted in carbon fixation rates as high as 14 g C/m^2-day associated with the rim of the Zhemchug Canyon. The movement of water masses contributes error to such an estimate and any one estimate should be considered cautiously. The average production rate for the seven stations along the southern transect using this method of estimation was 7.1 g C/m^2-day. Using a carbon to chlorophyll ratio of 30:1 (Steele 1974), the rate of change in standing crop phytoplankton biomass indicates a production rate of 83 mg C/m^2-day over the southern transect and a maximum 285 mg C/m^2-day at a station on the rim of the Zhemchug Canyon. These latter rates cannot be realistically viewed as primary production since they are the net result of growth, predation

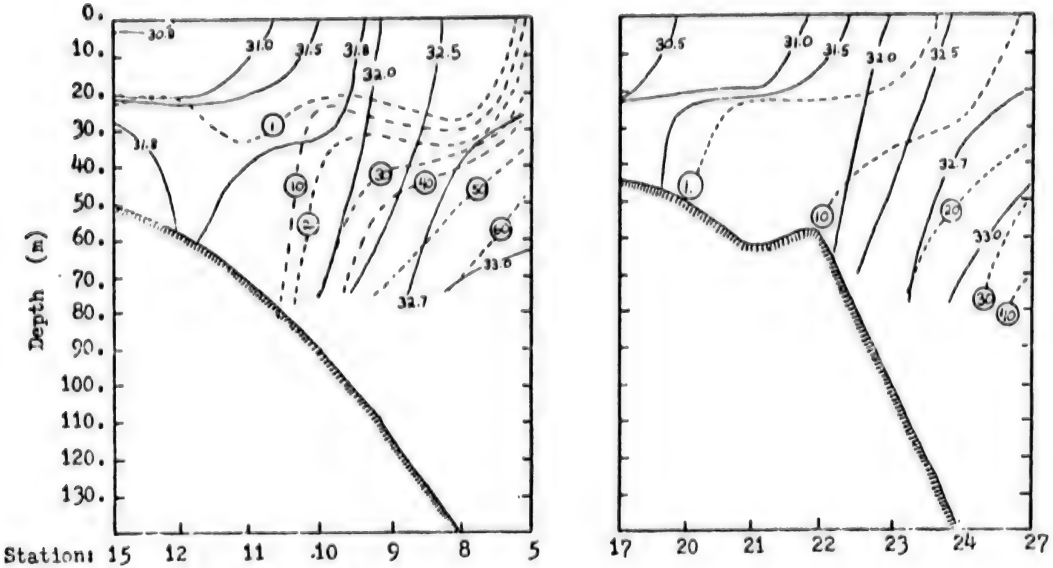

Figure 74. Comparison of nitrate and salinity isopleths.

A. Nitrate (as ug-at/l) isopleths seen here as broken lines and salinity (as ppt) isopleths in solid lines for the western transect from the first sampling. North is to the left in the figure.

B. Nitrate (as ug-at/l) isopleths seen here as broken lines and salinity (as ppt) isopleths in solid lines for the eastern transect from the first sampling. North is to the left while the area to the right represents the Zhemchug Canyon area.

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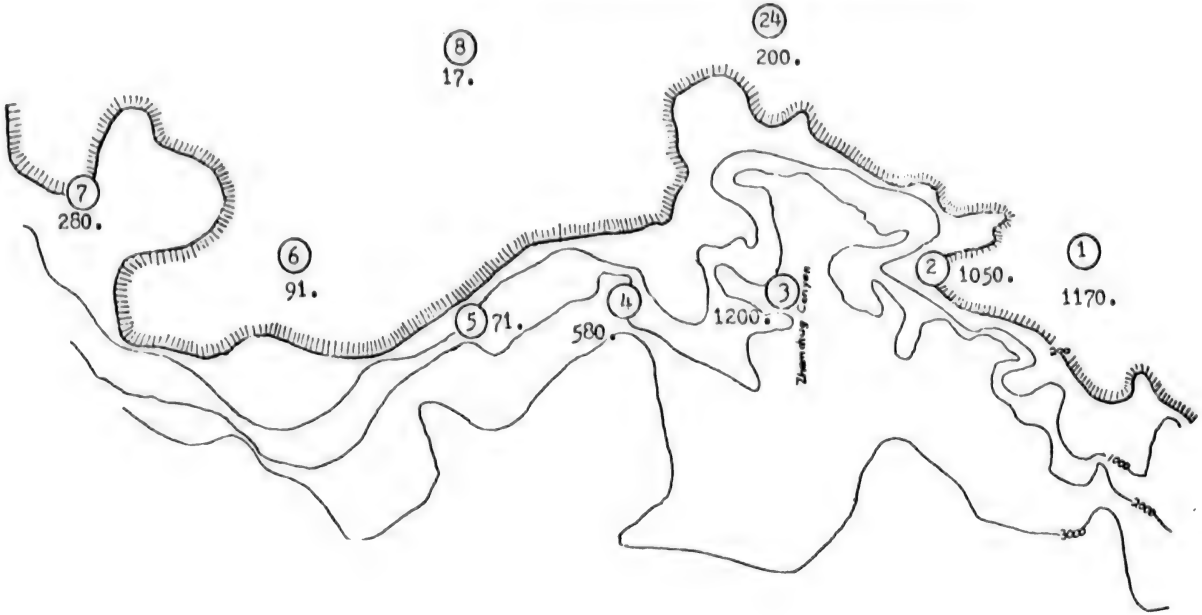

Figure 75. Zhemchug Canyon bathymetry and euphotic zone integrated nitrate concentrations. Station numbers and locations appear in circles. Euphotic zone integrated nitrate (as mg-at/m^2) appears as numbers associated with station positions.

and sinking processes. The decay of the nutrient pool towards the western limit of the southern transect was less dramatic. The euphotic zone in this region was comparatively lower in nutrients on the first sampling than that of stations farther east. A plot of isohaline and nitrate isopleths for the western north to south transect appears in Figure 76a. The agreement of isohaline and nutrient isopleths was not as strong as that for the eastern north to south transects. The euphotic zone of the western north-south transect on the initial sampling was comparatively nutrient poor.

Upwelling areas are typically dominated by diatoms (Nelson and Goering 1978). Subarctic Pacific phytoplankton are primarily composed of diatoms and dinoflagellates (Marumo and Minoda 1976; Motoda and Minoda 1974). The latter authors found the highest densities of diatoms (10^9 cells/m^3) associated with the area of continental slope proximal to stations 4, 5, 6 and 7 in this study. The organism primarily responsible for the increase in chlorophyll a at stations along the southern transect was the diatom Rhizosclenia hebetata.

Nelson and Goering (1978) found that in upwelling areas silica generally plays an important role in controlling primary production and phytoplankton species succession. In this study such a controlling relationship between silicon and primary production was suggested through multiple regression analysis where the rate of change of silica accounted for 64% of the variance in the positive rate of change of chlorophyll.

The concentration of nutrients found in the euphotic zone at stations in the region of the Zhemchug Canyon during the first sampling (NO_3: 20-60 ug-at/l; PO_4: 1.6-3.8 ug-at/l; Si: 1.5-2.1 ug-at/l) are typical of those found in the peruvian upwelling (Walsh 1975). The concentration of nutrients present in the euphotic zone after the formation of the thermocline in spring could not be expected to result in the observed distribution in late summer and clearly reflect recent input.

An upwelling event at the Zhemchug Canyon is evident the hydrographic, nutrient and biological data:

(1) The sigma-t isopleths for the southern west to east transects (Fig. 25) indicate an upward intrusion of comparatively dense water, appearing as finger-like projections in isopleths. An inshore movement of bottom water and a smaller offshore movement of surface water is indicated in calculated geostrophic velocities.

(2) Concentrations of nutrients in the euphotic zone at stations in the region of the Zhemchug Canyon during the first sampling were higher than would be expected given summer stratification and compare well to concentrations found in the Peru Coastal upwelling. Nutrient vertical isopleths are approximately parallel to salinity isopleths near the canyon.

(3) The rapid utilization of these nutrients by diatoms and the suspected controlling influence of silica on primary production adds additional support.

A continuous input of nutrients into the euphotic zone was not indicated in the canyon and thus it is suspected that upwelling is not a stable feature. The mechanism that drives the upwelling is not known but probably involves interactions of the wind field, the general counter clockwise circulation pattern that is fed by the Amchitka Pass to the south and the topography of the continental slope. The direction and speed of the wind in this area during the week prior to sampling is not known. Wind velocities of 2-8 m/sec from 300° - 360° were measured during the two days of sampling in the region of the canyon.

The importance of upwelling to harvestable production relates to the influx of nutrient mass that effectively permits accelerated primary and secondary production and minimizes the importance of short-term nutrient cycling for sustained primary production (Redfield et al. 1963). Further, ecological efficiency as it relates to harvestable biomass increases as the number of trophic levels tend to decrease in these areas.

In the most recent budget of primary production in the Bering Sea prepared by McRoy and Goering (1976), summer (61 days) production for combined oceanic and shelf areas is given as 50×10^{6} metric tons of carbon. This estimate was based upon ^{14}C

primary production measurements in the inner shelf and southern Aleutian Basin. If the 13% of Bering Sea area that is continental slope is considered separately with a production rate of 1 g C/m^2-day, McRoy and Goering's estimate for summer production is increased 22% to 61 metric tons of carbon.

An analysis of the features of the horizontal distribution of dominant species of phyto- and zooplankton showed that zones of the study area which differed in abiotic characteristics differed also in the composition and amount of planktons.

Plankton

Among the phytoplankton, oceanic species of diatoms and peridiniae predominated. The most abundant species at the edge of the shelf were Rh. hebetata, Ch. concovicornia, and C. tripos. In the interior of the shelf in the shallow part, C. oculus iridis, Th. sp., and C. tripos dominated. The maximum populations of C. oculus iridis and Thalassiosira sp. were found in cold waters with low salinity and high nitrite content. At the edge of the shelf the populations of these algae were substantially lower.

Even more marked differences between shallow water and deep-water parts of the polygon were found in the analysis of the distribution of zooplankters. Oceanic forms such as C. cristatus, E. bungii, and Th. longipes occurred only in region near the edge of the shelf; the typically neritic organisms -- the larvae of benthic invertebrates and E. nord manni -- were encountered only in the shallows. The largest variety of

neritic forms of zooplankters were encountered near the islands of North Lavrentiya and North Matveys. Among the most dominant species some had their high populations at the edge of the shelf (O. similis), and others in the shallows. The population of dominant species of zooplankters was markedly higher at the edge of the shelf (9500 organisms per cubic meter) than in the depth (2500 organisms per cubic meter).

The results obtained indicate the existence of two distinct communities -- neritic and oceanic -- of inhabitants of the area of the Bering Sea which was examined. In the greater part of the polygen a neritic community was observed, and characteristic features of an oceanic community were observed in the depth region.

Heinrich, (1962), exploring the basic planktonic communities of the Pacific Ocean, pointed out that in the community of the oceanic zone of the Bering Sea the biomass of phytoplankton was small. Large-sized, herbivourous copepods dominated (Calanus cristatus, C. plumchrus, and E. bungii). In the community of the neritic zone the biomass of zooplankton per unit area of sea was less than in the oceanic zone, whereas the biomass of phytoplankton was higher than in the oceanic zone. The number of species was not great, and there were often many heterotophic organisms.

Syomina (1955) noticed the confinement of neritic phytoplankters in the summer period to waters over the shelf.

He pointed out that the distribution of neritic species was limited to waters of the shelf; whereas oceanic species found favorable conditions for development in littoral and in oceanic waters. This explains the large quantity of oceanic phytoplankters found in the neritic community.

The data which we obtained on the distribution and abundance of dominant species of phyto- and zooplankters confirms the normal distribution of planktonic communities in the Bering Sea (Syomina 1955; Heinrich 1962).

Among the important distinguishing characteristics of the communities which we observed were the time-variability of the species composition and abundance of the plankton in the shallow regions of the study area as compared to the situation in deep water. This evidently is the result of the more active dynamics of the water in the deep part of the polygon, in the zone of influence of the Transverse Current. In the shallow area, the current is very weak and apparently cannot significantly change the characteristics of the community in a given zone by way of introducing plankton from other regions. Local changes in the community which occurred over the period between samplings (7 days) were small, apparently due to the low temperature of the water and concomitant slowing of the development of the plankton.

and little renewal from the relatively warm and nutrient rich source water in this area.

Strong evidence of previously unreported upwelling along the continental slope and in particular in the region of the Zhemchug Canyon is found in nutrient and density distributions and geostrophic current velocities. Primary production rates on the order of several grams carbon per square meter per day are reflected in the decay of nutrient concentrations in the euphotic zone along the continental shelf. Silica concentrations appear to exert a controlling influence on chlorophyll production in this area.

Nitrogen and phosphorus are removed from seawater in a mean 18.8:1 ratio. Nitrogen and silica are removed in a mean 1.3:1 ratio.

While nutrient cycling may accomodate primary production on the upper shelf, nutrient influx resulting from upwelling along the continental slope permits accelerated secondary productivities. The 13% of the Bering Sea area that is continental slope has not previously been considered separately in carbon production budget estimates for the Bering Sea.

McRoy and Goering's (1976) summer primary production estimate of 50 x 10^6 metric tons of carbon would be increased by 22% if a conservative interpretation of the data presented here is considered.

Hydrocarbons and benz(a)pyrenes in seawater are of biogenic

origin, with the latter exhibiting identical concentration in both seawater and atmosphere of 0.02%.

Further, the organic aerosols formed from the surface microlayer contribute along with salt particles to the ocean atmosphere. These ocean-formed organic aerosols range in size from 0.3 to 2u.

Atmospheric sulfur dioxide results from natural processes involving the emission of reduced sulfur from seawater and their subsequent atmospheric oxidation.

For clean, open oceanic regions, the atmospheric trace metal content correlates with the concentration in the water.

Among the phytoplankters of the study area the oceanic species predominated. The typical oceanic species, Coscinodiscus oculus iridus, had maximum population densities in the depths of the shelf, in cold waters with low salinity. At the edge of the shelf the population of this species was insignificant.

The population of the dominant species of zooplankton reached the maximum at the edge of the shelf (9500 organisms per cubic meter). In the depth of the shelf, the population was less (2500 organisms per cubic meter).

The distribution of a number of oceanic species of zooplankters (Calanus cristatus, E. bungii, and Thysanoessa longipes was limited to the very deepest part of the polygon near the edge of the shelf. The cosmopolitan species, Oithona similis, had it maximum population near the edge of the shelf and over the shelf its population was reduced. The neritic species, Acartia longiremis,

and heterotrophic organisms prevailed over the shelf in the shallow part of the polygon.

The characteristics of the plankton (species composition and biomass) inhabiting the shallow part of the polygon were less variable with time than those of plankton inhabiting the area near the edge of the shelf in the deep part of the polygon. This is connected with the more active dynamics of the water near the edge of the shelf in the zone of influence of the Transverse Current.

In summary, the Bering Sea is a somewhat pristine situation relevant to the pollutants measured. However, as has been demonstrated throughout the rest of the world acut short term pollutants are controllable. The impact of chronic exposure to pollutants either in a continuous low (or high) dosage is the major factor resulting in irreversible damage to the biosphere. It therefore behooves the scientific community to closely monitor short term levels, acute levels, acute sporadic levels and chronic pollutants which have caused both extinction and irreparable harm to the biosphere. We should not accelerate the extinction of life but rather cultivate life on earth.

V. SUMMARY

Three distinct water masses - coastal, shelf and Alaskan Stream - were present in the study area. Coastal water located in the northeast region of the study area is characterized by low salinity and strong thermal and halo stratification. Shelf water, characterized by strong thermal and weak halo stratification, was located wouth of St. Lawrence Island to approximately the 100m isobath. The area south of the 100m isobath to the southern limit of the sampling grid along the continental slope is considered Alaskan Stream water having comparatively weak thermal stratification and little halo stratification.

The strong density stratification associated with shelf waters presents an effective barrier to sinking phytoplankton and the vertical transport of nutrients. The depth of the mixed layer, the euphotic zone and nutrient concentrations increased towards the continental slope.

Geostrophic flow calculations indicated a general counter clockwise circulation in the area of source water and the low shelf area. This pattern of flow was previously reported in the Aleutian Basin.

Although a general northward flow towards the Bering Strait seems apparent, a southward countercurrent along the Alaskan coast is suggested from geostrophic flow calculations and is supported by the salinity distribution of the area to the southeast of St. Lawrence Island.

The maintenance of a cold ($< 0^{\circ}C$) water mass to the southwest of St. Lawrence Island indicates an unequally distributed northward flow

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VII. APPENDICES

Laboratory Automation Method

Submersible probe. An IBM computer with a serial I/O adapter, 5103 printer, 5106 auxiliary tape drive unit and a 7406 Device Coupler served as the nucleus of the system for automated control of data acquisition. The IBM 5100 was programmed in APL and had a 64K (K=1024 bytes) internal workspace. Magnetic tape cassettes were used for permanent storage. The IBM 7406 Device Coupler permits the interfering of digital and analog laboratory equipment to a computer and provides the pathways for a two directional flow between computer and analytical equipment. Although the Device Coupler has been used to automate analytical equipment in the laboratory (Brown, 1977), this was the first application of this apparatus in the field. The IBM 7406 Device Coupler configuration included an Analog Input Module (AIM), A Digital Input Module (DOM) and a Digital Output Module (DOM).

An Interocean Systems oceanographic and water quality system consisting of the model 514D digital readout and data scanners, 513D probe package, 510 submarine illuminance system, Oseas winch and submersible pump was selected for automation. The 513D probe package contained potentiometric probes for the measurement of conductivity, salinity, temperature, pH, dissolved oxygen, turbidity and depth. The printer output of the Interocean 514D digital readout and data scanner provides positive logic, parallel BCD output for the four digits of its display as well as channel identification, decimal point location and a positive going print pulse. The 514D permits external scan control to advance channels and to reset the channel bank by the leading edge of a 5v pulse on either the ADVANCE IN or CONTROL IN lines of the printer output. Recorder putputs provide analog signals for each channel. More detailed descriptions of the IBM 7406 and the Interocean 514D and 513D is presented by Guido and Cole (1975).

Seven input characters of the DIM were used in the link with the 514D: four characters for numerical data and the others for channel identification, decimal point location and for program control. A user generated control character that was interpreted in software to continue or exit the program was generated by switches and a 5 volt source in the wiring interface box (Fig. 76) where character bit lines of the 514D printer output were connected to the character input bit wires of the DIM cable. The negative print pulse required by the DIM was obtained internally from the same integrated circuit that produces the 514D's positive print pulse. The INHIBIT line of the DIM, which is normally low when data is being acquired and goes high following acquisition, was connected to the 514D's ADVANCE IN line to advance the channels of the 514D in a rapid channel advance-data acquisition loop (Fig. 77). Upon the reception of a print pulse emitted by the 514D, the INHIBIT line of the DIM went low during data acquisition from the "loaded" channel. When the data had been accepted the INHIBIT line went high stimulating a channel advance. Upon the reception of another print pulse the cycle was repeated. A twelve statement APL program provided the instructions for the 7406 to receive data from the 514D and to stimulate scanning of the seven channels. The program scanned the seven channels every four seconds with each scan requiring less than one half second. After each scan the control character was checked by the program and data acquisition was continued or termined. Upon termination, a subprogram was called to order the data by depth and then print the data with an identifying header. Longer and more involved programs were originally designed to accept data from preprogrammed depths and to interpret the control character in greater detail. These programs, however, decreased the scanning frequency and thus were forgone in the interest of speed.

The IBM-Interocean system collected and stored conductivity, salinity, temperature, dissolved oxygen, pH, turbidity, and light profiles with depth

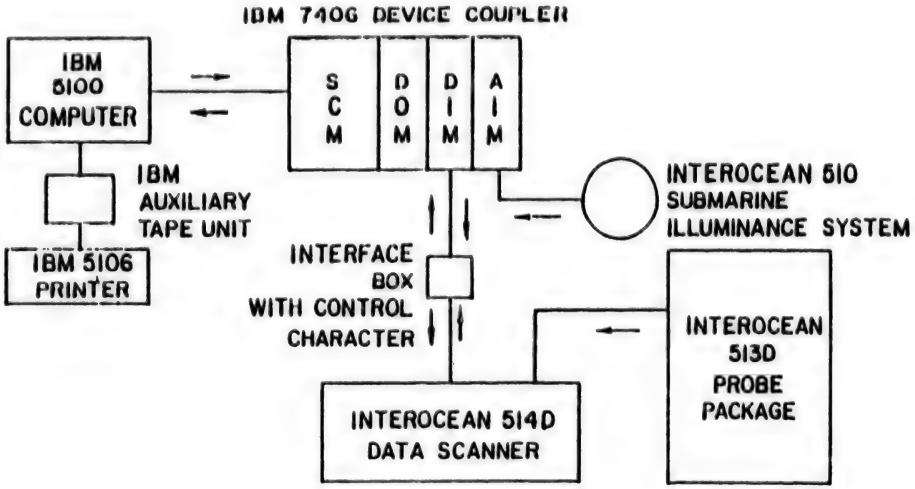

Figure 76. IBM computer and interface - Interocean probe data acquisition system.

249

BEST

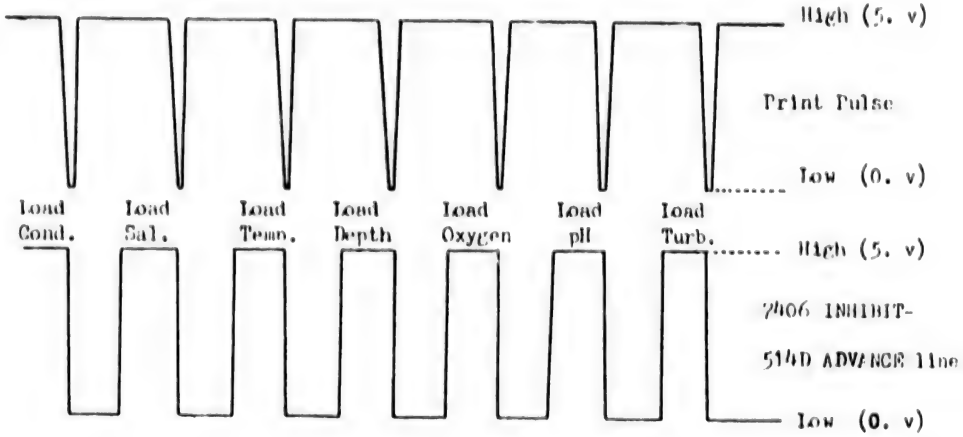

Figure 77. IBM computer and interface - Interocean probe system data acquisition loop.

while on station. The quick responding probes of the Interocean 513D probe package and the rapid channel scanning capability of the Interocean 513D-IBM 7406 permitted data collection from all probes at discrete depths while the probe package was being lowered through the water column.

The IBM-Interocean system (Fig. 77) accommodated two-way information flow. Commands for data acquisition, contained in the APL programs of the 5100, were executed by the 7406. Data from the channel scanning of the 513D by the 514D was transmitted to the 7406 via the DIM and AIM and then to the 5100 computer for storage on magnetic tape cassettes and printing.

Nutrient analysis system. Two Technicon triple track AAII systems for the determination of ammonia, nitrate, nitrite, orthophosphorous, silica and dissolved organic carbon in seawater were interfaced with the IBM equipment (Fig. 78) In the AAII system there is one sampler for three analytical units. Each test is composed of a reagent mixing module and a colorimeter. The seawater samples taken from a sampling tray are peristaltically pumped through the system and after being mixed with colorimetric reagents are passed on to a colorimeter. Recorders receive a voltage from the colorimeter and transmit it via a transmitting potentiometer to the modular printer. The sampling in each of the two systems is done at a regular interval, the length of which is determined by the type of analysis being performed (20-120 samples/hour). Though sampling for each of the three channels in AAII system is synchronous, the time at which the reagent-sample mix enters the colorimeter differs for each unit. The modular printer of the AAII system controls the sampling rate and accepts data from the recorders. The printers must be manually stimulated to accept the first peak reading from each track and thereafter maintain synchrony with the colorimeters and recorders. The modular printer does not lend itself directly to automation with this type of system. Further, the computer interface outputs of the modular printer transmit data serially and were not exploited here.

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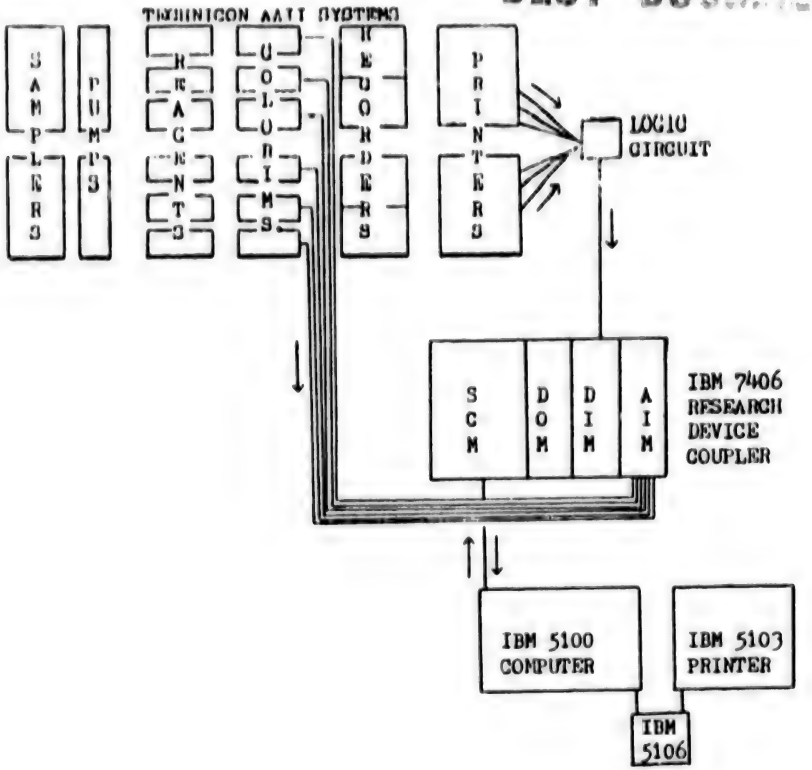

Figure 78. IBM computer and interface - Technicon Autoanalyzar data acquisition system.

Analog data could be obtained directly from the colorimeters from an additional 0-5V full scale output. However, the six colorimeters each produced relevant data at a regular interval but all at different points in time. The problem of obtaining the correct information at the appropriate time was solved by designing a small logic circuit. "Sample" pulses were obtained from the circuit boards of the modular printer to stimulate the 7406 to receive data from the colorimeter when the printer "sampled" the recorder of that track. To obtain the "sample" pulse the modular printers had to be partially disassembled and modifications made on three circuit boards of each printer. These signals were conducted to a logic circuit (Fig. 79) which provided the DIM with a print pulse and bit pattern to identify the signaling channel. The 0-5V full scale output voltage of the colorimeter was scaled down by means of resistors and Trimpots to 0-2V full scale to accommodate the AIM input limit. The modular printers were used to maintain synchrony on each channel of the autoanalyzer. When the printer "sampled" a colorimeter, the DIM was stimulated to read the digital bits provided by the six "sample" lines from the printers. After identifying the signaling channel the appropriate colorimeter data was read through the AIM. An APL program provided the instructions for data acquisition.

The APL programs used in these systems were interactive and permitted the operator to enter station number, location coordinates, time, depth and some meteorological information prior to the start of a run while on station. The Interocean and Technicon systems could not be operated simultaneously under IBM 5100-7406 control. However, this was of little consequence since the water samples for nutrient analysis were collected by the submersible pump of the Interocean 513D while the IBM-Interocean system was profiling. Turning the IBM equipment over to the Technicon system required only the switching of plugs into the DIM and AIM of the 7406 and loading the corresponding APL workspace with the programs for the Technicon system. The IBM 5100 computer provided the

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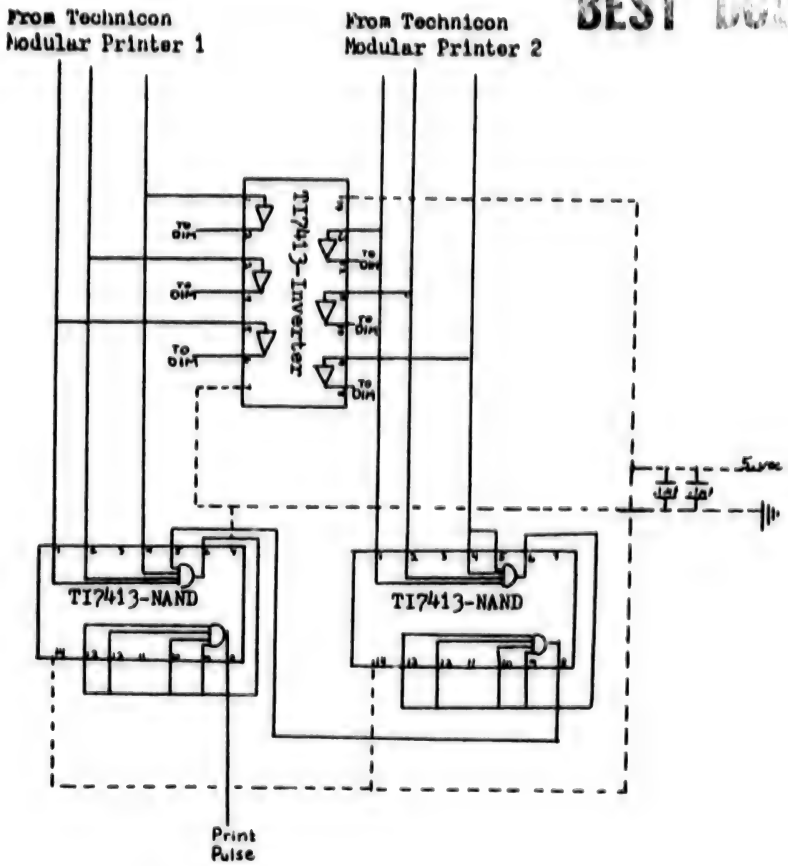

Figure 79. Logic circuit for IBM-Technicon system.

expedition with secreterial and statistical services while serving as the nucleus for the automated system. Hydrocarbon and metal data collected by other scientists on the expedition in addition to data acquired through automation, were stored on tape in files by oceanographic station. Multiple copies of the data were generated at the IBM 5103 printer between stations and distributed among the Soviet and U.S. Scientific personnel. Statistical analysis, calculations for known addition methods and measurement corrections were performed on the 5100 while at sea. Inherent to this programmed system was a flexibility that accommodated modifications while at sea.

The setup procedures for the system were straightforward and relatively uncomplicated. Most of the required wiring connections were made and the system assembled and checked out during the two weeks prior to the start of the expedition. The system was packed and transported to the Volna where the reassembly of this system took less than one day.

Observations on the Automated Oceanographic Laboratory

The overall compatability and performance of the IBM 7406 and the Interocean 514D was excellent. The ability to rapidly scan the quick responding probes of the 513D probe package eliminated problems typically encountered when profiling with recorders. Taking discrete data from recorders is a tedious and time consuming task often complicated by the effect of the ship's motion on vertical profiles. This type of data collection system would appear to be the successor to recorder systems in light of the development and increasing acceptance of new potentiometric probe methods for seawater analysis.

This system would be well suited to the needs of smaller research vessels. The entire laboratory system (computer, printer, coupler and digital readout) requires only six cubic feet of space.

Sampling not by a flexible protocol involving the recognition of certain physical, chemical or biological phenomena (thermocline, chlorophyll maxima etc.) is an application that this system would permit but was not exploited here. Oceanographic sampling is often done in relation to physical and biological phenomena. Sampling criteria and sampling point recognition could be incorporated in the programming and executed while profiling through an electrically stimulated sampling device (e.g. Niskin Rossette type). The Technicon AAII systems did not lend themselves to this type of automation. Problems with maintaining synchrony between the Technicon printer and recorders and a floating baseline required much of the data to be ultimately taken from the recorders. The Technicon AAII is one of the older Technicon analysis systems whose use in seawater analysis is likely to be succeeded by the Technicon Aqualyzer. The Aqualyzer was used as a backup system on the expedition and would appear to be more compatible with this type of automating system.

Table Results of nutrient and chlorophyll a analysis

STA.	DEPTH	SI ug-at/l	NH3 ug-at/l	NO2 ug-at/l	NO3 ug-at/l	PO4 ug-at/l	CHL A ug /l
1	SURF.	10.0	.2	.2	35.0	2.7	.66
1	10	12.8	.5	.3	43.0	2.7	.97
1	25	21.0	1.1	.4	61.0	3.4	.39
1	50	41.0	1.1	.8	105.0	4.6	.36
1	75	57.0	.8	.3	130.0	5.3	.08
2	SURF.	6.0	2.2	.2	32.0	2.2	.13
2	10	16.0	3.7	.4	43.0	3.2	.11
2	25	19.0	5.1	.4	53.0	3.8	.25
2	50	57.0	3.6	.4	83.0	4.8	.12
2	75	61.0	4.0	.3	86.0	5.2	.10
3	SURF.	2.5	3.0	.2	45.0	1.7	.34
3	10	1.5	3.9	.2	45.0	1.6	.25
3	25	2.2	4.5	.2	55.0	1.8	.09
3	50	12.6	7.5	.3	57.0	3.0	.11
3	75	31.0	8.5	.4	56.0	4.2	.06
4	SURF.	2.3	1.2	.3	22.0	2.1	.29
4	10	3.1	1.6	.3	23.0	2.0	.32
4	25	4.3	1.8	.3	24.0	2.1	.47
4	50	34.5	3.9	.6	58.0	4.0	.12
4	75	51.0	1.9	.4	74.0	4.4	.13
5	SURF.	5.0	.7	.2	15.0	1.6	.21
5	10	4.0	.9	.3	24.0	1.8	.31
5	25	15.0	2.1	.5	44.0	3.1	.30
5	50	33.5	2.2	1.3	66.0	4.4	.10
5	75	44.0	1.5	.2	73.0	4.6	.13
6	SURF.	1.7	1.6	.2	.5	.6	.18
6	10	5.0	1.6	.1	.5	.3	.73
6	25	5.5	3.6	.2	11.0	1.2	.18
6	50	36.0	2.8	.4	59.0	4.6	.06
6	75	54.0	1.9	.3	74.0	5.1	.09
7	SURF.	1.0	1.2	.2	9.5	1.3	.37
7	10	1.0	1.2	.2	9.5	1.2	.47
7	25	2.0	1.0	.2	15.0	1.5	.43
7	50	33.0	2.2	.4	58.0	4.1	.06
7	75	72.0	1.0	.4	68.0	4.4	.16

Table Cont.

STA.	DEPTH	SI ug-at/l	NH3 ug-at/l	NO2 ug-at/l	NO3 ug-at/l	PO4 ug-at/l	CHL A ug /l
8	SURF.	3.0	.5	.2	.5	2.5	.39
8	10	3.0	.7	.2	.7	2.5	.41
8	25	3.0	2.0	.2	.8	3.0	1.02
8	50	36.0	5.8	.3	47.0		.16
8	75	84.0	4.0	.3	68.0	3.1	.15
9	SURF.	6.5	1.8	.2	.2	1.1	.43
9	10	7.0	1.8	.1	.2	1.0	.10
9	25	7.0	1.8	.1	2.5	.8	.21
9	50	56.0	4.2	.2	49.0	2.5	.03
9	75	83.0	5.0	.2	54.0	2.9	.14
10	SURF.	.5	1.5	.1	.4	1.0	.24
10	10	.5	1.6	.1	.2	.1	.21
10	25	5.3	2.3	.2	14.0	1.0	.17
10	50	10.5	4.0	.2	27.0	3.6	.53
10	75	12.5	4.7	.3	30.0	4.1	.29
11	SURF.	1.4	.3	.1	.5	.9	.22
11	10	1.2	.4	.1	.5	.8	.37
11	25	1.1	.6	.1	1.0	1.0	.19
11	50	11.5	2.1	.2	3.1	3.7	.74
11	75	13.5	2.2	.2	3.1	3.9	.72
12	SURF.	.5	.3	.0	.2	1.3	.15
12	10	.5	.3	.0	.2	1.3	.74
12	25	5.5	.5	.2	8.0	2.7	7.80
12	50	6.0	.8	.2	11.0	3.1	2.70
13	SURF.	3.5	.5	.1	.3	1.4	.10
13	10	3.0	.4	.1	.2	1.3	.56
13	25	2.0	.5	.1	.2	1.8	3.88
13	50	17.5	.4	.3	32.0	4.2	4.30
13	75	17.5	.4	.3	32.0	3.7	4.40
14	SURF.	2.5	.8	.1	.2	1.3	.18
14	10	2.0	.6	.1	.2	1.2	2.95
14	25	2.6	.7	.1	.7	2.4	6.70
14	50	13.5	.7	.5	16.0	3.5	1.92

Table cont.

STA.	DEPTH	SI ug-at/l	NH3 ug-at/l	NO2 ug-at/l	NO3 ug-at/l	PO4 ug-at/l	CHL A ug/l
15	SURF.	1.3	.6	.0	.5	1.1	.10
15	10	1.2	.4	.0	.5	1.1	2.40
15	25	3.5	.6	.2	3.0	2.3	12.10
15	45	3.5	.7	.2	3.0	2.4	.41
16	SURF.	1.0	.6	.1	.2	1.3	.15
16	10	.8	.6	.1	.2	1.4	1.50
16	25	3.5	.7	.3	3.0	2.4	10.60
16	45	4.0	.8	.3	3.5	2.7	10.80
17	SURF.	1.0	.8	.1	.3	.8	.21
17	10	1.0	.6	.1	.3	.8	.19
17	25	.9	.8	.1	.8	1.7	1.68
17	40	.8	.9	.1	.8	1.8	.75
18	SURF.	1.5	1.0	.1	.2	.9	.30
18	10	1.5	.6	.1	.2	.8	.78
18	25	.9	.6	.1	.2	1.5	.62
18	35	.9	.7	.1	.2	1.5	1.08
19	SURF.	1.5	.8	.1	.4	.5	.31
19	10	1.5	.7	.1	.3	.4	.64
19	25	1.5	.6	.1	.2	.4	.75
20	SURF.	.5	.8	.1	.2	.3	.12
20	10	1.0	.8	.1	.2	.3	.08
20	25	1.0	1.2	.3	.5	.6	2.60
20	45	1.0	1.3	.3	.5	.7	.77
21	SURF.	.5	.8	.1	.2	.5	.21
21	10	.5	.7	.1	.3	.5	1.27
21	25	8.5	2.3	.2	6.0	.9	1.53
21	50	9.0	2.5	.2	6.5	.9	1.17
21	58	9.0	2.5	.2	6.5	1.2	.79
22	SURF.	.4	1.5	.1	.2	.4	.61
22	10	.5	.9	.1	.2	.5	.73
22	25	.7	1.3	.2	1.5	.7	.73
22	30	1.0	1.8	.2	3.0	1.0	1.41

Table cont.

STA.	DEPTH	SI ug-at/l	NH3 ug-at/l	NO 2 ug-at/l	NO3 ug-at/l	PO4 ug-at/l	CHL A ug/l
23	SURF.	3.0	.8	.1	.2	.4	.47
23	10	2.5	1.5	.1	.2	.3	1.34
23	25	9.0	1.5	.2	5.7	1.3	1.96
23	50	38.0	3.8	.2	18.0	2.8	.27
23	75	45.0	5.6	.4	18.0	3.1	.14
24	SURF.	.4.3	1.4	.2	7.5	.9	1.12
24	10	4.2	.9	.2	7.5	1.2	.50
24	25	7.5	1.1	.3	9.5	1.4	.43
24	50	37.0	1.9	.5	20.0	2.5	.19
24	75	51.5	1.3	.3	25.0	2.8	.11
25	SURF.	.5	.4	.1	.4	.7	1.92
25	10	.5	.3	.1	.4	.6	2.10
25	25	.8	.9	.1	2.2	1.0	.92
25	50	40.0	.7	.7	21.0	3.4	.26
25	75	49.0	.6	.1	24.0	4.2	.26
26	SURF.	.5	.9	.3	4.5	.9	3.35
26	10	.5	1.1	.3	4.7	.9	2.88
26	25	4.5	1.2	.3	8.1	1.3	1.08
26	50	32.5	2.0	.5	20.0	2.4	.23
26	75	60.0	1.1	.1	26.0	3.2	.10
27	SURF.	4.0	.7	.2	13.0	1.0	.20
27	10	3.8	.8	.2	13.0	.9	.54
27	25	4.0	1.0	.2	15.0	1.2	.38
27	50	24.8	2.4	.3	31.0	2.5	.39
27	75	63.5	2.8	.4	43.0	3.3	.14
28	SURF.	4.2	1.0	.2	14.5	1.2	1.33
28	10	4.0	1.0	.2	13.5	1.1	.62
28	25	13.0	1.2	.3	24.0	1.5	.59
28	50	41.0	1.2	.6	42.0	2.5	.29
28	75	52.0	.7	.2	48.0	2.7	.20
29	SURF.	4.8	.5	.2	14.0	1.2	.39
29	10	4.5	.5	.2	15.0	1.1	.51
29	25	5.8	.9	.2	15.5	1.2	.63
29	50	38.0	1.9	.6	37.0	2.5	.17
29	75	43.7	1.4	.5	43.0	2.6	.21

Table cont.

STA.	DEPTH	SI ug-at/l	NH3 ug-at/l	NO2 ug-at/l	NO3 ug-at/l	PO4 ug-at/l	CHL A ug/l
30	SURF.	.4	1.4	.1	.5	.4	.88
30	10	.2	.9	.1	.5	.3	1.16
30	25	.8	1.0	.2	8.5	.7	.98
30	50	12.8	4.0	.3	27.5	2.1	.42
30	75	45.0	2.7	.2	44.0	2.9	.11
31	SURF.	1.4	1.7	.2	2.0	.8	1.44
31	10	1.3	1.9	.2	2.0	.7	.84
31	25	2.0	1.7	.3	5.0	.8	.44
31	50	20.8	3.5	.4	18.0	2.2	.21
31	75	39.7	2.3	.5	26.0	2.6	.13
32	SURF.	.5	1.6	.1	46.0	.2	.22
32	10	.3	1.3	.1	.3	.2	.30
32	25	.5	1.4	.1	.2	.3	.60
32	50	18.5	5.2	.3	18.5	2.2	.22
32	75	39.0	4.1	1.7	13.2	2.7	.15
33	SURF.	1.7	1.3	.1	.2	.2	.69
33	10	1.5	1.1	.1	.2	.2	.64
33	25	1.7	1.0	.1	.2	.2	2.95
33	50	29.4	6.1	.3	18.0	2.3	.25
33	75	49.4	7.0	.2	20.0	2.5	.11
34	SURF.	.4	1.5	.1	.3	.2	.39
34	10	.1	.8	.1	.2	.2	.21
34	25	.6	1.1	.2	.2	.3	.52
34	50	13.3	3.8	.3	12.0	1.7	.73
34	75	20.0	4.9	.3	12.0	1.8	.24
35	SURF.	1.9	.9	.1	.1	.7	.24
35	10	.4	.9	.1	.1	.5	.24
35	25	1.0	.8	.1	.2	.5	.87
35	50	13.3	2.5	.2	11.6	1.9	.12
35	75	13.6	2.7	.2	11.7	2.0	.33
36	SURF.	.5	1.0	.1	.2	.8	.20
36	10	.4	.7	.1	.4	.7	.78
36	25	2.2	1.0	.2	4.1	1.3	7.78
36	50	9.2	1.2	.2	8.7	1.4	2.39

Table cont.

STA.	DEPTH	SI ug-at/l	NH3 ug-at/l	NO2 ug-at/l	NO3 ug-at/l	PO4 ug-at/l	CHL A ug/l
37	SURF.	5.2	.9	.1	.1	.7	.24
37	10	5.2	.8	.1	.1	.6	.18
37	25	7.8	.9	.3	2.8	1.2	1.72
37	50	24.5	1.0	.3	12.3	2.1	3.01
37	75	24.7	.8	.3	12.3	2.2	1.40
38	SURF.	1.4	.9	.1	.2	.7	.24
38	10	1.3	1.0	.1	.2	.7	.45
38	25	5.4	1.1	.2	1.8	1.2	7.60
38	50	11.0	1.3	.5		1.6	2.25
39	SURF.	1.1	1.2	.1	.3	.7	.04
39	10	1.1	1.0	.1	.3	.7	.16
39	25	5.0	.9	.3	1.0	1.2	.23
39	45	4.6	1.0	.3	.6	1.3	1.06
40	SURF.	.2	.9	.1	.2	.5	.25
40	10	1.0	.8	.1	.7	.6	.38
40	25	4.0	1.3	.3	.4	1.2	2.35
40	40	4.3	1.5	.3	.5	1.2	1.18
41	SURF.	1.0	.5	.1	.2	.4	.28
41	10	1.0	.7	.1	.2	.4	.46
41	25	1.8	.8	.1	.3	.8	.42
41	44	1.7	1.3	.1	.3	.9	.75
42	SURF.	1.4	.5	.1	.1	.5	.04
42	10	1.3	.6	.1	.1	.4	.02
42	25	1.2	1.0	.1	.1	.7	.15
42	35	1.3	1.0	.1	.4	.7	.19
43	SURF.	2.4	.8	.1	.1	.4	.26
43	10	2.0	.6	.1	.1	.4	.66
43	25	2.6	1.0	.1	.1	.4	.88

Table cont.

STA.	DEPTH	SI ug-at/l	NH3 ug-at/l	NO2 ug-at/l	NO3 ug-at/l	PO4 ug-at/l	CHL A ug/l
44	SURF.	.7	.7	.1	.1	.4	.34
44	10	.3	.7	.1	.1	.4	.14
44	25	.7	.6	.1	.1	.4	.69
44	45	.9	1 0	.1	.5	.5	1.33
45	SURF.	.4	.4	.1	.1	.5	.22
45	10	.3	.4	.1	.1	.4	.39
45	25	4.4	1.0	.1	3.2	1.0	.83
45	50	6.5	1.8	.1	4.0	1.2	.92
46	SURF.	1.3	.7	.1	.1	.6	.48
46	10	1.4	.8	.1	.1	.5	.89
46	25	4.6	2.4	.2	3.7	1.1	.92
46	50	5.6	2.9	.2	4.6	1.3	.81
47	SURF.	1.3	.6	.1	.1	.3	1.02
47	10	1.3	.7	.1	.1	.3	1.20
47	25	7.0	1.1	.2	5.0	1.0	1.81
47	50	47.2	6.0	.4	20.0	3.0	.43
47	75	47.5	7.6	.4	23.0	3.1	.20
48	SURF.	4.0	1.1	.2	5.0	1.0	1.55
48	10	5.0	.6	.2	5.0	1.0	.35
48	25	10.0	.9	.4	11.0	1.5	.78
48	50	30.3	1.4	.7	27.0	2.4	.23
48	75	42.0	1.2	.2	23.0	2.8	.29

		O_2 ml/l						PO_4 at/l			Si at/l		
Sta. #	Depth	USA	USSR		USA	USSR		USA	USSR		USA	USSR	
1	2	3	4	5	6	7	8	9	10	11	12	13	14
11	0	8.20	8.33	-0.13	6.99	7.03	-0.04	0.90	0.33	0.57	1.4	6.3	-4.9
	10	8.00	8.48	-0.48	7.03	7.08	-0.05	0.80	0.33	0.47	1.2	8.4	-7.2
	25	8.10	8.33	-0.23	8.36	8.44	-0.08	1.0	0.68	0.32	1.1	9.4	-8.3
	50	7.54	7.95	-0.41	6.59	6.70	-0.11	3.7	0.95	2.75	11.5	18.8	-7.3
	75 (60)	7.51	7.92	-0.41	6.22	6.93	-0.71	3.9			13.5	25.1	-11.6
12	0	8.07	8.27	-0.20	7.05	7.23	-0.18	1.30	0.49	0.81	0.50	6.3	-5.80
	10	8.07	8.41	-0.34	7.05	7.17	-0.12	1.30	0.82	0.48	0.50	6.3	-5.80
	25	7.84	8.24	-0.40	8.74	9.30	-0.56	2.70	1.00	1.70	5.50	14.7	-9.20
	50	7.65	8.00	-0.35	7.21	7.74	-0.53	3.10	1.12	1.98	6.00	18.0	-12.0
	75												
13	0	13.27	8.22	5.05	7.38	7.34	0.04	1.40	0.53	0.87	3.50	6.3	-2.80
	10	13.23	8.46	4.77	7.38	7.36	0.02	1.30	0.49	0.81	3.00	6.3	-3.30
	25	13.80	8.21	5.59	10.59	9.60	0.99	1.80	0.94	0.86	2.00	8.5	-6.50
	50	14.58	7.90	6.68	6.16	6.70	-0.54	4.20	1.05	3.13	17.5	11.5	-6.0

St. #	Depth	pH. USA	pH. USSR		O^2 ml/l USA	O^2 ml/l USSR		PO^4-P at/l USA	PO^4-P at/l USSR		Si at/l USA	Si at/l USSR	
1	2	3	4	5	6	7	8	9	10	11	12	13	14
4	0	8.25	8.35	-0.10	7.04	6.93	0.11	2.10	0.79	1.31	2.3	6.3	-4.0
	10	8.26	8.36	-0.10	7.06	7.05	0.03	2.0	0.80	1.20	3.1	6.3	-3.2
	25	8.26	8.36	-0.10	7.26	7.17	0.09	2.1	0.98	1.12	4.3	14.3	-10.0
	50	8.08	8.23	-0.15	7.50	7.16	0.34	4.0	1.78	2.22	34.5	41.9	-7.4
	75	7.98	8.09	-0.11	6.60	6.82	-0.22	4.4	2.06	2.34	51.0	52.4	-1.4
5	0	8.33	8.31	0.02	7.08	7.11	-0.03	1.6	0.66	0.94	5.0	6.27	-1.27
	10	8.31	8.32	-0.01	7.02	7.10	-0.08	1.8	0.80	1.00	4.0	7.3	-3.3
	25	8.24	8.10	-0.14	7.31	7.00	0.31	3.1	1.06	2.04	15.0	17.1	-2.1
	50	8.06	8.13	-0.07	6.88	6.60	0.28	4.4	1.61	2.79	33.5	44.0	-10.5
	75	7.97	8.07	-0.10	6.00	6.46	-0.46	4.6	1.98	2.62	44.0	54.4	-10.4
6	0	8.41	8.28	-0.13	6.97	7.02	-0.05	0.60	0.49	0.11	1.7	7.3	-5.6
	10	8.42	8.37	-0.05	6.95	6.95	0.00	0.30	0.66	-0.36	5.0	6.3	-1.3
	25	8.40	8.38	-0.02	7.86	7.86	0.00	1.2	1.70	-0.50	5.5	14.6	-9.1
	50	8.06	8.13	-0.07	7.30	7.18	0.12	4.6	2.43	2.17	36.0	37.7	-1.7
	75	7.98	8.03	-0.05	6.49	6.75	0.26	5.1	2.57	2.53	54.0	56.5	-2.5
7	0	8.35	8.18	0.17	7.11	7.15	-0.04	1.3	0.63	0.67	1.0	6.3	-5.3
	10	8.36	8.33	0.03	7.19	7.27	-0.08	1.2	0.82	0.38	1.0	10.9	-9.9
	25	8.36	8.34	0.02	7.54	7.60	-0.06	1.5	1.28	0.22	2.0	17.8	-15.8
	50	8.06	8.14	-0.08	7.04	7.45	-0.41	4.1	1.94	2.16	33.0	41.9	-8.9
	75	8.03	8.10	-0.07	6.72	7.24	-0.52	4.4	1.94	2.46	72.0	62.8	-9.2

Station Number	Depth	O_2 ml/l USA	O_2 ml/l USSR		O_2 ml/l USA	O_2 ml/l USSR		PO_4-P at/l USA	PO_4-P at/l USSR		Si at/l USA	Si at/l USSR	
I	2	3	4	5	6	7	8	9	10	11	12	13	14
	0	8.27	8.28	-0.01	7.65	6.93	0.72	2.7	0.66	2.04	10.0	9.43	0.57
	10	8.26	8.25	0.01	7.73	7.08	0.65	2.7	0.66	2.04	12.8	9.00	3.8
	25	8.22	8.18	0.04	8.07	7.23	0.84	3.4	0.79	2.61	21.0	12.2	8.8
	50	8.04	8.01	0.03	7.00	6.70	0.00	4.6	1.45	3.15	41.0	39.80	1.2
	75	7.97	7.90	0.07	6.32	6.12	0.02	5.3	1.78	3.56	57.0	54.4	2.6
2	0	8.24	8.12	0.12	7.47	7.03	0.44	2.2	0.95	1.25	6.0	6.27	-0.27
	10	8.24	8.19	0.05	7.54	6.03	1.51	3.2	1.06	2.14	16.0	6.27	9.73
	25	8.23	8.22	0 01	7.81	7.46	0.35	3.8	1.20	2.60	19.0	9.57	9.43
	50	8.16	8.15	0.01	8.08	6.94	1.14	4.8	1.28	3.52	57.0	25.1	31.9
	75	8.01	8.05	0.04	6.89	6.17	0.72	5.2	1.70	3.50	61.0	44.0	17.0
3	0	8.25	8.19	0.06	7.40	6.95	0.45	1.7	0.66	1.04	2.5	7.3	-4.8
	10	8.27	8.24	0.03	7.42	7.25	0.17	1.6	0.58	1.02	1.5	6.8	-5.3
	25	8.29	8.29	0.00	7.6[illegible]	7.59	0.26	1.8	0.54	1.26	2.2	9.4	-7.2
	50	8.18	8.29	-0.11	0.07	7.55	-7.48	3.0	0.82	2.18	12.6	12.6	0.0
	75	8.06	7.92	0.14	7.24	6.96	0.28	4.2	1.54	2.66	31.0	27.2	3.8

Sta #	pH. Depth	USA	USSR		O_2 ml/l USA	USSR		PO_4 at/l USA	USSR		Si at/l USA	USSR	
1	2	3	4	5	6	7	8	9	10	11	12	13	14
8	0	8.	8.	0.15	6.9	7.0	-0.11	2.5	0.33	2.17	3.0	6.1	-3.1
	10	8.40	8.36	0.04	6.95	7.22	-0.27	2.5	0.33	2.17	3.0	6.1	-3.1
	25	8.42	8.32	0.10	7.08	7.44	-0.36	3.0	1.62	1.38	3.0	10.0	-7.0
	50	8.11	8.12	-0.01	7.44	6.04	1.40	-	2.24	-	36.0	20.7	15.3
	75	7.79	7.98	-0.01	6.29	6.12	0.17	3.1	2.34	0.76	84.0	60.7	23.3
9	0	8.47	8.32	-0.15	6.99	7.13	-0.14	1.1	0.49	0.61	6.5	8.4	-1.9
	10	8.49	8.48	-0.01	6.99	7.19	-0.20	1.0	0.49	0.51	7.0	8.4	-1.4
	25	8.43	8.38	0.05	8.31	7.68	0.63	0.80	1.20	-0.40	7.0	18.8	-11.8
	50	8.02	8.03	-0.01	7.00	6.89	0.11	2.5	2.43	0.07	56.0	49.2	-6.8
	75	7.95	8.05	-0.10	6.24	7.04	0.80	2.9	2.47	0.43	83.0	49.2	33.8
10	0	8.39	8.23	0.16	6.88	6.93	-0.05	1.0	0.16	0.84	0.5	4.4	-3.9
	10	8.40	8.40	0.00	6.89	6.98	-0.09	0.10	0.16	-0.06	0.5	4.2	-3.7
	25	8.48	8.40	0.08	7.65	8.36	0.71	1.0	0.42	0.58	5.3	16.8	- 11.5
	50	8.06	8.13	0.07	6.91	7.45	-0.54	3.6	1.12	2.48	10.5	20.6	-10.4
	75	8.04	8.13	-0.09	6.65	7.50	-0.85	4.1	1.28	2.28	12.5	22.8	-10.3

Stn. #	Depth	O_2 ml/l USA	O_2 ml/l USSR		O_2 ml/l USA	O_2 ml/l USSR		PO_4 at/l USA	PO_4 at/l USSR		Si at/l USA	Si at/l USSR	
1	2	3	4	5	6	7	8	9	10	11	12	13	14
14	0	-	8.32	-	7.00	7.34	-0.34	1.30	0.66	0.64	2.50	5.2	-2.70
	10	-	8.47	-	7.40	7.27	0.13	1.20	0.66	0.54	2.00	5.2	-3.20
	25	-	8.34	-	10.40	9.76	0.64	2.40	0.79	1.61	2.60	8.9	-6.30
	50	-	9.95	-	6.49	6.79	-0.30	3.50	0.82	2.68	13.5	11.5	-2.00
15	0	19.31	8.35	10.96	7.08	7.03	0.05	-	0.59	-	-	8.4	-
	10	19.04	8.46		7.11	7.02	0.09	-	0.59	-	-	9.4	-
	25	18.76	8.22		9.57	9.66	-0.09	-	0.71	-	-	11.5	-
	50												
	75												
16	0	-	8.27	-	7.04	6.93	0.11	1.30	0.16	1.14	1.00	7.3	-6.30
	10	-	8.43	-	7.11	7.08	0.03	1.40	0.16	1.26	0.80	8.4	-7.60
	25	-	8.04	-	9.04	8.33	0.71	2.40	0.59	1.81	3.50	19.4	-15.9
	50 (40)	-	8.02	-	7.80	8.06	0.26	2.70	0.76	1.94	4.00	27.2	-23.2
	75												

					O_2 ml/l			PO at/l			Si at/l		
Sta. #	Depth	USA	USSR		USA	USSR		USA	USSR		USA	USSR	
1	2	3	4	5	6	7	8	9	10	11	12	13	14
17	0	-	7.99	-	7.06	6.83	0.23	-	0.59	-	-	8.4	-
	10	-	8.17	-	7.04	6.98	0.06	-	0.8[illegible]	-	-	6.3	-
	25	-	8.10	-	8.19	8.76	-0.57	-	0.9[illegible]	-	-	7.5	-
	50												
	75												
18	0	-	7.92	-	6.89	-	-	0.90	0.16	0.74	1.50	1.0	-0.40
	10	-	8.07	-	6.87	6.94	-0.07	0.80	0.43	0.37	1.50	3.1	-1.60
	25	-	8.10	-	8.40	8.83	-0.43	1.50	0.72	0.78	0.90	5.5	-4.60
	50												
	75												
19	0	-	[illegible]	-	8.37	7.46	0.91	0.50	0.33	0.17	1.50	7.3	-5.80
	10	-	8.39	-	8.36	8.46	-0.10	0.40	0.49	-0.09	1.50	7.3	-5.80
	25	-	8.13	-	9.23	8.46	-0.77	0.40	0.15	0.24	1.50	6.3	-4.80
	50												
	75												

Sta. #	Depth	USA	USSR		O_2 ml/l USA	USSR		PO_4 at/l USA	USSR		Si at/l USA	USSR	
1	2	3	4	5	6	7	8	9	10	11	12	13	14
21	0	-	8.18	-	8.10	6.95	1.15	0.30	0.33	- 0.03	0.50	7.3	-6.8
	10	-	8.27	-	8.10	6.89	1.21	0.30	0.33	-0.[illegible]	1.0	7.3	-6.3
	25	-	8.16	-	9.96	7.92	2.04	0.60	0.49	0.11	1.0	7.8	-6.8
	50												
	75												
22	0	-	8.26	-	8.19	7.03	1.16	0.50	0.66	-0.11	0.50	6.3	-5.8
	10	-	8.34	-	8.24	6.98	1.26	0.50	0.49	-0.00	0.05	6.3	
	25	-	8.06	-	9.98	8.36	1.62	0.90	0.51	0.39	8.50	12.7	-4.2
	50	-	8.02	-	9.02	8.30	0.72	0.90	0.66	0.24	9.00	16.8	-7.8
	75												
23	0	-	8.25	-	8.85	7.39	1.46	0.40	0.33	0.07	0.40	8.4	-8.0
	10	-	8.34	-	8.82	8.08	0.74	0.50	0.33	0.17	0.50	8.8	-8.3
	25	-	8.24	-	9.51	8.16	1.35	0.70	1.08	-0.38	0.70	9.2	-8.5
	50	-	-	-	9.20	-	-						
	75												

Sta. #	Depth	USA	USSR		USA	O_2 ml/l USSR		PO_4 at/l USA	USSR		Si at/l USA	USSR	
1	2	3	4	5	6	7	8	9	10	11	12	13	14
23	0	-	8.38	-	8.28	6.93	1.35	0.40	0.16	0.24	3.00	6.5	-3.5
	10	-	8.44	-	8.32	7.08	1.24	0.30	0.16	0.14	2.50	6.3	-3.8
	25	-	8.34	-	9.29	7.40	1.89	1.30	0.28	1.02	9.00	11.9	-2.9
	50	-	8.03	-	7.47	6.89	0.56	2.80	0.63	2.17	38.0	27.2	10.8
	75	-	7.97	-	7.31	6.43	0.88	3.10	0.79	2.31	45.0	42.3	2 7
24	0	-	8.22	-	8.35	7.03	1.32	0.90	0.16	0.74	4.30	6.3	-2.0
	10	-	8.31	-	8.32	7.08	1.24	1.20	0.20	1.00	4.20	6.3	-2.1
	25	-	8.28	-	8.71	7.63	1.08	1.40	0.26	1.14	7.50	15.2	-7.7
	50	-	8.14	-	8.54	7.26	1.28	2.50	0.95	1.55	37.0	37.7	-0.7
	75	-	8.02	-	7.56	6.48	1.08	2.80	1.94	0.86	51.5	46.1	5.4

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As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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